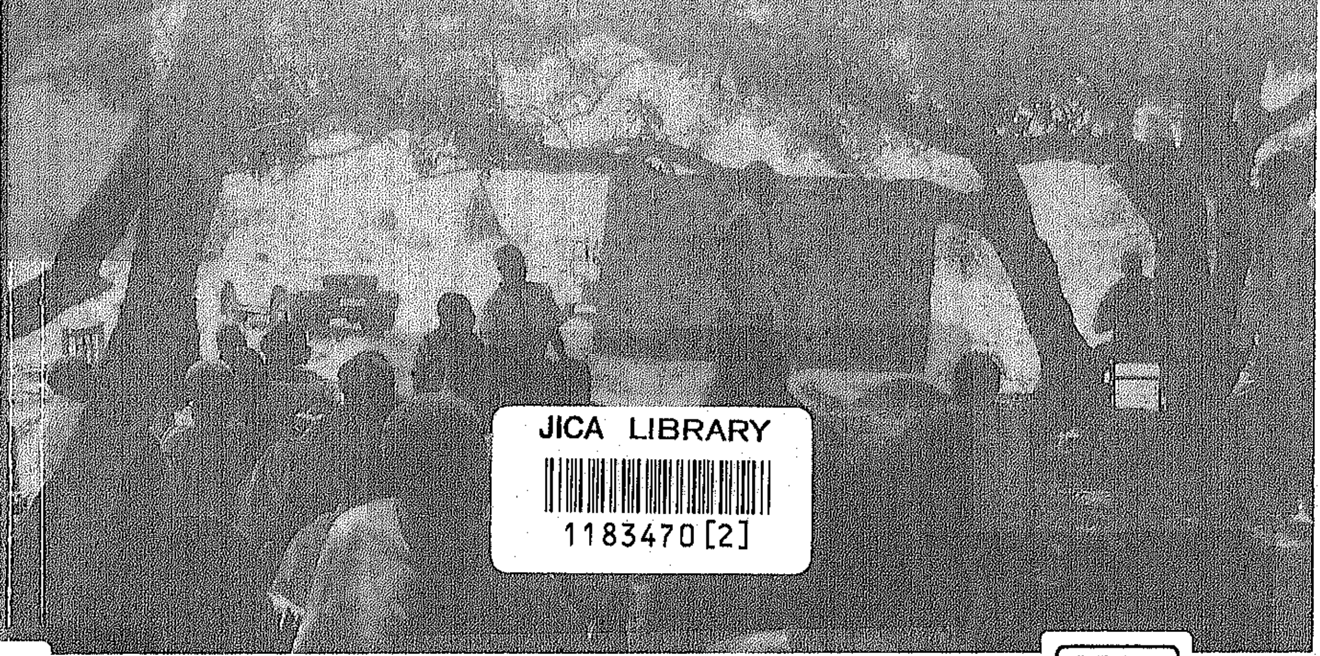
SUSTAINABLE AGRICULTURE TECHNOLOGIES (SAT) FOR SUB-SAHARAN AFRICA





September 2006

Japan International Cooperation Agency
Regional Support Office for Eastern and Southern Africa

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for
Sub-Saharan Africa

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This booklet is a supplementary text for "Participatory Approach to Sustainable Village Development (PASVID)" which was published in March 2006. It is intended for use in Sub-Saharan Africa. The JICA Project for "Participatory Village Development in Isolated Areas (PaViDIA)" prepared a draft manual called "Sustainable Agriculture Practices – Field Manual". This SAT has been written for Sub-Saharan Africa with reference to the PaViDIA manual.

This book was compiled by the Agriculture and Rural Development Team in the JICA Regional Support Office for Eastern and Southern Africa, made up of Niki Hikaru (Ph.D.), Furuichi Shingo and Silas Irea. However, useful contributions were made by the PaViDIA Project in Zambia, especially Mr. Matsuda Akira and Mr. C. Chizyuka. This book is therefore the fruit of the joint efforts of the PaViDIA Project and the JICA Regional Support Office.

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ABBREVIATIONS AND ACRONYMS

ACIAR	Australian Centre for International Agricultural Research
ADC	Annual Depreciation Cost
ADP	Animal Draft Power
ASAL	Arid and Semi-Arid Lands
ATSC	Australian Tree Seed Centre
C/N Ratio	Carbon/Nitrogen Ratio
CSIRO	Commonwealth Scientific and Industrial Research Organisation
CTFT	Centre Technique Forestier Tropical
DANIDA	Danish International Development Assistance
FAO	Food and Agriculture Organization (of the United Nations)
HDRA	Histoculture Drug Response Assay
IAA	Integrated Agriculture-Aquaculture
ICRAF	International Centre for Research in Agro-Forestry
IPM	Integrated Pest Management
IPP	Initial Purchase Price
JICA	Japan International Cooperation Agency
K	Potassium
KARI	Kenya Agricultural Research Institute
KES	Kenya Shilling(s)
N	Nitrogen
NGO	Non-Governmental Organization
OFI	Oxford Forestry Institute
P	Phosphorus
PASViD	Participatory Approach to Sustainable Village Development
PVC	Poly-Vinyl Chloride
PaViDIA	Participatory Village Development in Isolated areas
SAT	sustainable Agriculture Technologies
SSA	Sub-Saharan Africa
SV	Salvage Value
UK	United Kingdom
UL	Useful Life
USA	United States of America
cm	Centimetre
ha	Hectare
hr	Hour
kg	Kilogramme
mm	Millimetre
°C	Degrees Celsius
pH	Acidity or Alkalinity
t	ton

PREFACE

In an effort to tackle the problem of poverty and hunger in Sub-Saharan Africa (SSA), the manual on "Participatory Approach to Sustainable Village Development (PASViD)" was revised and published in March 2006. The book presented the theory and practice needed to achieve autonomy and prosperity at the village level in the region. But while the manual states that sustainable agriculture is a prerequisite to attain sustainable village development, it remains silent on the technical aspects of sustainable agriculture.

This book, "A Technical Guide for Sustainable Agriculture" is a supplement to the PASViD manual, and is expected to complete the course for sustainable village development which is the basis for decreasing poverty and hunger.

The farming techniques which extension officers recommend to farmers must be clear, easy to understand, attainable and beneficial to the farmers. Any such technique must assure the farmer of sustained increases in food production and incomes, as well as improvements in soil productivity, environment, human health and compatibility with social circumstances. This book further highlights the importance of evaluating the costs and benefits of each recommended technique.

In preparing this book, substantial contributions were made by the experts working in the project on "Participatory Village Development in Isolated Areas (PaViDIA)" in Zambia. The book has benefited greatly from their precious experiences and lessons.

We are grateful to Mr. Y. Teranishi, the Representative of our office, for his encouragement to compile this book. We also wish to thank most sincerely our office administrative staff, headed by Ms. Y. Saito, who undertook the backstopping work to publish the book.

It is our hope that this book will be utilized together with the PASViD textbook. Although this SAT text book could be used individually, village development through projects like PASViD may enhance and accelerate effectiveness and efficiency substantially. PASViD and SAT could be viewed as ship (transportation means) and cargo (contents), respectively. We further hope that practitioners in agriculture and rural development will not keep it in shelves, but instead will carry it to the field where the methods and techniques it expounds are most needed and applied.

Nairobi
August 2006

Agriculture and Rural Development Team
JICA Regional Support Office for Eastern and Southern Africa

CHAPTER 1:

INTRODUCTION

1.1 Definition of Agriculture and Sustainable Agriculture

Agriculture is the cultivation of the land in order to grow crops or raise livestock as a source of food or other useful products such as fibre, e.g. wool or cotton. In the process of practicing agriculture, there are many undesirable effects on the land, the environment and people. For example, it is estimated that over one third of all useable land worldwide has been seriously degraded in the last 100 years by unsustainable farming practices. It is further estimated that over 300 tons of productive topsoil are lost worldwide every minute, from accelerated erosion, related to destructive agricultural practices that have gone on since the 1940's.

In order to stop or minimise these undesirable effects of agriculture, the trend is now to adopt practices that make agriculture sustainable so that the land can continue producing. To be sustainable, the system must also be basically organic, that is, based on what occurs within the local ecosystem naturally, not dependent on externally produced inputs or support systems such as chemical fertilizer or manufactured chemical crop protection materials. It means relying on the natural systems that have evolved over very long periods of time, during which organisms and components have interacted and reproduced on a continuing basis.

The sustainable agriculture movement identifies three areas of concern that must be addressed by our agricultural system - economics, environment, and social structure. A sustainable agriculture is that which provides a fair and reasonably secure living for farm families; it should benefit rather than harm the natural environment and must at least maintain basic natural resources such as healthy soil, clean water, and clean air; and it should support viable rural communities and fair treatment of all involved in the food system, from farm workers to consumers.

The practice of sustainable agriculture can therefore be explained under the following fundamental principles (Figure 1):

Soil productivity

- farm productivity is enhanced over the long term through maintaining soil productivity by safeguarding its fertility and physical structure.

Economic profitability

- net social and economic benefits (in both monetary and non-monetary terms) from agriculture are maximised.

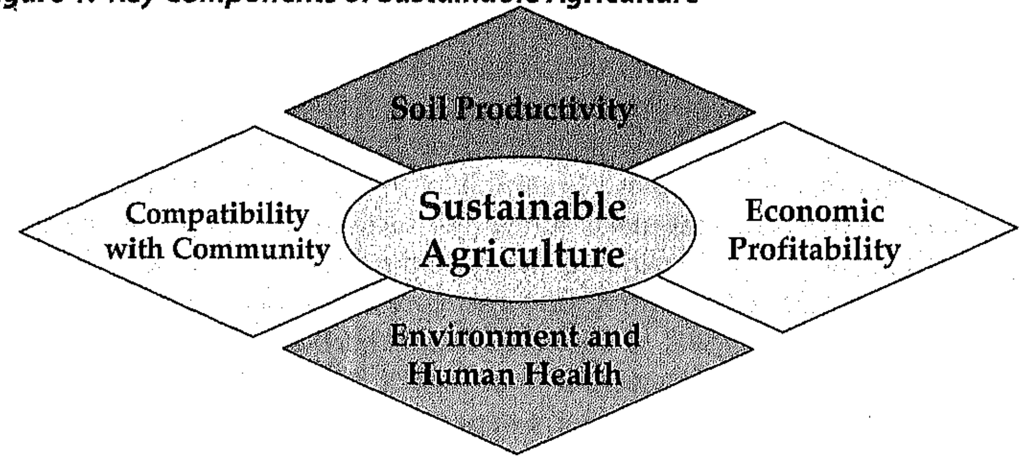
Environment and Human Health

- residues resulting from the use of chemicals in agriculture are minimised and not allowed to enter the food system.

Compatibility with community

- adverse impacts on community life, natural resource base and associated ecosystems are ameliorated, minimised or avoided.

Figure 1: Key Components of Sustainable Agriculture



1.2 The Soil as a Living Organism

The soil is virtually a living organism - a dynamic mass of organic, living material in an inorganic matrix. It is full of life. And it does not produce any food unless it is sustained in that living condition.

Soils are made of a mineral component and the organic matter component. Minerals begin as rocks which gradually break down into smaller and smaller particles - sand to silt to clay.

Organic matter from any plant or animal tissue is decomposed (i.e. broken down) by soil microbes and macrobes into smaller and smaller particles. These decomposing particles of organic matter eventually become humus.

During periods of very heavy rainfall, soils with high levels of humus will hold onto the plant nutrient ions so that these ions are not 'leached' out of the soil. This means that any synthetic fertilisers added to soils with high levels of humus will be stored more efficiently in the soil and will give much greater overall economic benefit to the farmer.

1.3 Need for Sustainable Agriculture

The lack of sustainable agriculture harms the environment by sucking rivers, lakes and underground water sources dry, increasing soil salinity and thereby destroying its quality, and by washing pollutants and pesticides into rivers destroying downstream ecosystems as far as corals and breeding grounds for fish in coastal areas.

It is for these reasons that the productivity of the land must be improved. Fertile land is so limited that productivity of existing agricultural areas will have to increase to meet ever-growing needs of a growing population especially in Sub-Saharan Africa (SSA).

CHAPTER 2:

MAINTAINING SOIL PRODUCTIVITY

2.1 Overview

(1) What Defines Soil Productivity?

Soil is the medium on which plants grow. A fertile soil will enhance plant growth and a poor soil will lead to poor or no growth at all. For plant growth to be optimal certain conditions of the soil must be fulfilled. Once they are fulfilled, the soil is said to be fertile and, if placed on a moderate slope or a well-drained flat, will produce as expected. They are:

- *Soil depth:* this is the exploitable volume of plant roots – the greater the volume, the more fertile the soil.
- *Availability of water:* moisture retention for continuous water supply to the plant.
- *Drainage:* most crops cannot survive in waterlogged soils.
- *Aeration:* This is necessary for healthy root growth and high activity of soil life.
- *pH* (range of acidity): the soil should neither be too acidic nor too alkaline.
- *Mineral composition:* has an influence on the nutrients released by weathering, the nutrient holding capacity and the soil structure.
- *Content of organic matter:* has an influence on the nutrients released by decomposition, the nutrient holding capacity, water retention, soil structure and soil life.
- *Activity of soil organisms:* these are crucial for nutrient availability, water retention, a good soil structure, decomposition of organic material and soil health.
- *Contamination:* high concentration of salts, pesticides or heavy metals can inhibit plant growth.

In summary, soil productivity is defined by the presence of the right chemical content, the desired physical structure and location.

(2) How to Maintain Soil Fertility

Farmers can improve the fertility of their soil by use of various management practices which must aim to achieve the following:

- Protection of the soil from strong sunlight and heavy rain by means of plant cover e.g. mulching with plant residues, green manure crops or cover crops, in order to prevent soil erosion and to preserve soil moisture.
- A balanced crop rotation or mixed cropping: a suitable sequence of annual crops grown on a field for preventing a depletion of the soil nutrients.
- An appropriate tillage method: suitable for getting a good soil structure without causing erosion and compaction.
- A good nutrient management: application of manures and fertilizers according to the demands of the crops in their respective growth stages.
- Balanced feeding and protection of soil organisms: enhancing the activity of beneficial soil microbes and organisms like earth worms by supplying organic material.

(3) How to Increase the Amount of Organic Matter in the Soil

1) Description

Organic matter permanently undergoes a process of decomposition. In order to maintain and increase the content of soil organic matter, organic material must be applied again and again. The speed of decomposition depends on the climate and on how green the material is – the C/N ratio. In warm and damp conditions, the organic matter is broken down much faster than in cold or dry conditions.

2) Procedure

The following activities increase the level of organic matter in the soil:

- leaving crop residues on the field, instead of burning or wasting them, as they are the major source of biomass.
- applying compost: this is very effective, as part of the organic matter in compost is already stabilized and will remain in the soil for a longer period than fresh plant material.
- applying organic manures: as they contain organic material, they help to increase the content of organic matter; at the same time, they can speed up decomposition as they are rich in nitrogen and thus stimulate soil organisms.
- mulching with plant materials or agro-wastes: especially applying hardy material (rich in fibre or wood) will increase the organic matter content, as it will remain in the soil for a longer time; in addition, it helps to reduce soil erosion.

- Using green manures or cover crops: green manures grown on the same field will contribute biomass both from the leaves and roots.
- Suitable crop rotation: including crops in the rotation which build up soil organic matter, especially perennials and crops with a dense root system (e.g. pastures).
- Reducing soil tillage: each tillage will speed up the decomposition of organic material, as it aerates the soil and stimulates soil organisms.
- Avoiding soil erosion: all methods listed above will be in vain unless soils are prevented from eroding away; erosion carries away those parts of the soil which contain most humus and are most fertile.

3) Costs and benefits

All the above procedures can be applied with minimal cost since materials for mulching and organic manures are available on the farm. The farmer uses family labour for all the procedures described.

4) Risks

There are no risks associated with the above activities.

2.2 How to Make Compost

1) Description

Compost is a mixture of decayed organic materials decomposed by micro-organisms in a warm, moist and aerated environment, releasing nutrients as readily available forms for use by growing plants.

2) Procedure

The traditional method of making compost requires 3-4 months before farm wastes are sufficiently decomposed and ready for use as compost fertilizer. The steps for making compost are:

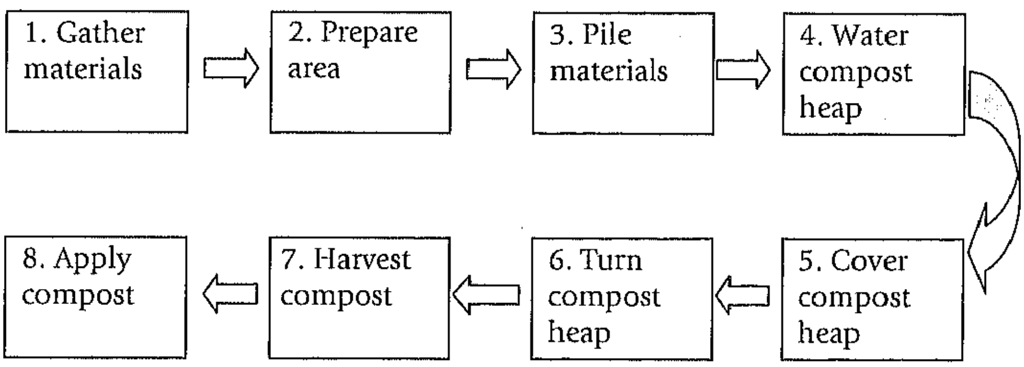
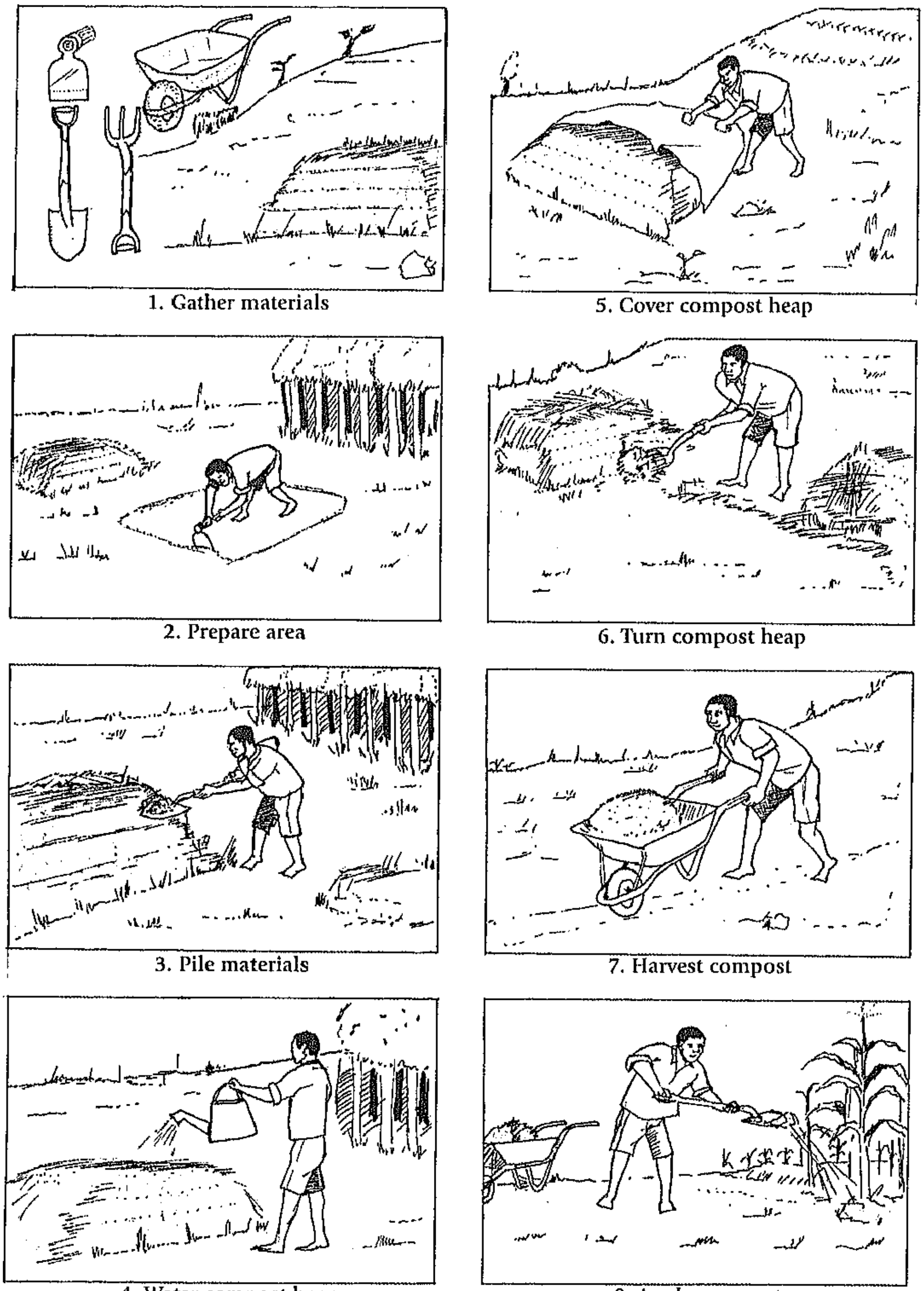


Figure 2.1: How to make compost



3) Costs and benefits

The traditional method of making compost as described above is inexpensive and requires no external inputs. Labour is provided by family members.

The benefits of using compost are:

i) The farmer makes savings and increases self-reliance.
ii) Crop yields are increased.
iii) It improves soil tilth and structure.
iv) It improves soil aeration.
v) It provides humus or organic matter, vitamins, hormones, and plant enzymes which are not supplied by chemical fertilizers.
vi) It acts as a stabilizer to changes in soil pH.
vii) It kills pathogenic organisms, weeds, and other unwanted seeds when temperatures of over 60°C are reached.
viii) It can be made out of different materials blended together to increase the nutrient content of the compost.

2.3 Organic Manure

1) Description

Manure is the excrement of animals or the decomposed crop residues and green vegetable matter. Green manure is that which is formed by ploughing into the ground a cover crop such as *Sesbania* spp. Manures are organic and include animal manures, compost, organic household wastes, agro-industrial residues, humus of earthworms and residues from wood.

Table 2.3: Chemical Composition of Animal Manure

Animal Manure	*C/N Ratio*	*Nitrogen N*	*Phosphorus P*	*Potassium K*
Cattle	19	1.50	1.00	0.94
Sheep	29	2.02	1.75	1.94
Horse	24	1.59	1.65	0.65
Pig	13	2.81	1.61	1.52
Chicken	-	4.00	1.98	2.32
Duck	-	2.15	1.13	1.15
Human*	8	7.24	1.72	2.41

Source: Gachene, Charles K. K. and Gathiru Kimaru, 1999.

Note

* Though human manure is treated and used in some Asian countries, it is not recommended for use in Africa because of the inadequacy of safe handling and therefore the obvious danger of spreading human disease.

2) Procedure

Animal droppings may be collected together daily and placed in a pit. They are then mixed with plant materials before they are covered with a thin layer of soil to accelerate decomposition.

Manure is treated by:

- Protecting it from the sun
- Protecting it from wind
- Mixing it with straw
- Avoiding water-logging where it is collected
- Allowing it to decompose in a pit where there is no in- or out-flow of water but good aeration
- Compressing it when it is dry
- Ensuring that the floor of the manure pit is solid
- Watering it to accelerate decomposition and release of nutrients for plant use.

3) How to Prepare Boma Compost from Fresh Livestock Droppings

i. Dig a pit 0.5 m deep behind the boma, putting the excavated soil beside the pit. The pit should be 1.5 m wide and any length, depending on the amount of material available for composting. Loosen the soil at the bottom of the pit and place a layer of dry crop residues like maize stover or grass at the bottom.

ii. Then place a layer of about 10 cm of fresh manure and bedding obtained from the boma.

iii. Cover this with a thin layer of topsoil (1-2 cm thick).

iv. Now add a 10 cm layer of manure and again cover with a thin layer of topsoil. Repeat the process until the compost heap is 1.5 m high.

v. When completed cover the pile with soil, then with grass, maize stalks or banana leaves to prevent drying. In the dry season, the pile should be watered regularly avoiding too much water in order to preserve the manure nutrients.

vi. Use a long pointed stick to monitor the temperature and moisture of the pile. Add water as soon as the stick feels dry. If there is no moisture, there is a whitish fungal mycelial layer showing on the stick.

vii. After two or three weeks, turn the pile into an adjacent pit and then into a third pit after a further two weeks. All the time the pile must be covered with grass or crop residues to prevent it from drying up.

viii. Three weeks after the second turning, use the stick to check the temperature. When the stick feels cool, the pile is ready for use. By now the compost should have a fresh earthy smell and no grass or animal droppings should be distinguishable. However, if the stick still feels warm to the touch, then the pile is still decomposing and requires more time.

4) How to Apply Compost or Manure

Once the compost is fully decomposed, it may be spread manually on the plot. It is then thoroughly mixed with the soil before a crop is planted. If all the compost cannot be applied, then it must be stored under shade so as to protect it from the sun and preserve its nutrients.

It is difficult to determine the amount of compost to apply to soil without knowing the nutrient content of both the soil and the manure. However, it is advised that one should spread a thin layer that covers the entire field when planting a field crop (maize, wheat etc). For tree crops, mixing with equal amounts of soil and putting in the pit during transplanting or placing it at the base of the tree and mixing it with soil (quantity may vary with age of the tree) are effective methods. Care should be taken for the manure not to touch the tree trunk. After application, the area should be watered so that root hairs can gain access to the nutrients in the manure.

5) Costs and benefits

The costs of making compost are minimal because all the raw materials are obtained from the farm and are wastes. The equipment used is also available on the farm. Labour is provided by the family. However, composting has the potential to be either a cost or a profit for a farming operation. The following questions enable a farmer to determine the likelihood of profiting from composting wastes.

- Is there an established requirement for cropland soil improvement in the area?
- Is there a need to control odour in the area?
- Are you able to use all the compost you make on your farm, and if not, are there nearby customers interested in compost?
- Is there a commitment to producing quality compost?
- Can it be a substitute for fertilizer for crops grown on your farm or in the area?

Composting reduces waste volumes while producing a stabilized humus. Benefits of composting include:

- It significantly reduces volume of wastes

- Easier to handle and store compared with raw manure
- Reduces risk of ground water contamination
- Eliminates weed seeds and almost all pathogens contained in the wastes used
- May reduce chemical fertilizer requirements
- Soil erosion control

The benefits of tilling the soil with compost include increasing the organic content of the soil while diminishing the occurrence of pests and weeds. Compost improves soil structure by expanding pore space and consequently aeration which enhances plant growth. Compost adds internal spaces to clay soils which assists in water penetration and drainage. Sandy soils benefit from increased water holding capacity and retention of nutrients. Compost is known to suppress many soil-borne plant diseases and this can reduce costs to purchase herbicides.

6) Risks

The most significant risk to widespread compost use is the unknown concentration of nutrients. Nutrient concentration and availability from manure is dependent upon animal diet, age, as well as type and quantity of bedding material present in manure.

Compost releases nutrients at a slower rate than chemical fertilizer or manure although release rates increase each successive year compost is added to the soil. Nitrogen loss is of particular concern and is partly due to microorganisms using nitrogen in wastes for rapid growth to degrade organic materials during the composting process.

CHAPTER 3:

SOIL EROSION AND DESERTIFICATION

3.1 Overview

(1) What is Soil Erosion?

Soil erosion is the removal of soil by gravity, water, wind or ice. It has two distinct phases: the detachment of individual particles from soil aggregates; and transport of the dislodged particles to a different place.

Large amounts of soil are eroded by water in different areas and soil types of SSA. The many different factors that interact to determine the amount of soil loss occurring at a particular time and place include rainfall erosivity, soil erodibility, topographic factors of slope gradient and length, and the type of land cover and crop management.

Erosive means tending to cause erosion and erodible means susceptible to erosion. Wind and water are erosive agents with heavy rainfall downpours with large drops being more erosive than soft small droplet rains. Strong winds are also more erosive than soft breezes. Soils tend to vary in their erodibility with deep well-formed soils that support plant cover and a developed plant root system being less erodible than exposed shallow soils.

(2) How to Identify Signs of Soil Erosion

The following signs help one to identify whether a field is affected by soil erosion:

- Deep gullies show severe and obvious soil erosion.
- Small grooves on the soil surface indicate significant losses of soil.
- A compact soil crust after a heavy rain is an indicator of probable soil erosion.
- Accumulation of the soil material in trenches and depressions is evidence of soil erosion in the immediate neighbourhood.
- Brown colour of the drainage water or streamlets during and after heavy rains is a reliable indicator of soil erosion in the watershed.
- Farmers say: "The stones are growing out of the soil" meaning that soil is being washed away and stones are thus being exposed.
- Roots of trees are partially exposed.

(3) Effects of Soil Erosion

Soil erosion leads to land degradation as a result of depletion of soil mass and nutrients. Highly degraded African soils have led to very low per capita food production. Smallholders have removed large quantities of nutrients from their soils without applying sufficient quantities of manure or fertilizer to replenish the soil. This has resulted in a very high average annual depletion rate – 22 kilograms of nitrogen, 2.5 kilograms of phosphorus and 15 kilograms of potassium per hectare of cultivated land over the last 30 years in 37 African countries – an annual loss equivalent to US$ 4 billion in inorganic fertilizer.

Fertilizers have been applied to counteract loss of nutrients but sustainable agriculture advocates minimal application or total avoidance of inorganic fertilizers. Productivity trends demonstrate that the benefits of science and technology in Africa have been captured most consistently in the commercial and irrigated farming systems where purchased inputs are used most extensively. In the more traditional upland rain-fed farming systems, there has been some limited success with root crops, especially in systems where cassava is the principal crop.

3.2 How to Prevent Soil Erosion

Soil erosion is prevented using three general strategies:

(1) Reducing the erosive power of the rain drops by keeping the soil covered with vegetation or mulch.

(2) Improving the infiltration of rain water into the soil by maintaining a good soil physical structure.

(3) Reducing the speed of the water flowing down the slopes with the help of structures (e.g. bench terraces, wooden barriers and stone walls, bunds and trenches).

(1) Keeping the Soil Covered

a. Using a cover crop

1) Procedure for keeping the soil covered with vegetation

In perennial plantations such as orchards, dense vegetation can be achieved by growing legumes, grass or creepers between the trees. In new tree plantations, fodder grass and arable crops such as tubers, pineapple, beans etc. can be grown until the trees develop a dense canopy. Grass too can provide a protective cover.

Where possible, weeding should be avoided during the rainy season in order not to expose the soil to the impact of the rain drops. In that case, weeds can be cut to reduce competition for nutrients with the crop.

2) Costs and benefits

There are no specific costs attached to growing a cover crop since the crop fits in the designed crop rotation for the farm. The benefits are that while protecting the soil from soil erosion, a crop is produced and nitrogen fixing bacteria lead to improvement of soil fertility. Cover crops, such as legumes, manage to suppress weeds in maize and increase grain yield. In addition, rye as cover crop is known to cause significant reduction of density and biomass of several weed species in maize and soybean because of its allelopathic effect.

3) Risks

There are no specific risks associated with planting a cover crop so long as the crop does not compete for nutrients with the main crop. Use only nitrogen-fixing cover crops as much as possible.

b. Mulching

1) Description

Mulching is the covering of the soil with cut plant material of any kind. The mulch eventually decomposes and turns to humus which improves soil fertility.

2) Procedure for using mulch

Cut the crop leftovers such as maize stover and spread them on the land after tilling. If a mulching grass has been planted, cut and spread it on the land. Note that mulching materials brought from outside of the farm can easily introduce new weeds on your land.

3) Costs and benefits

Mulching should be done with crop leftovers after harvesting. The cost associated with this practice is therefore minimal. Family labour is used to collect the leftovers and spread them on the land. The main benefits are that owing to its coverage of the soil surface, mulch is very effective in protecting the soil from erosion. Mulching also prevents raindrops from injuring the surface structure. Once it decomposes, mulch adds humus to the soil and thus improves soil fertility. Mulch also smoothers weeds and thus prevents them from growing and competing with the crop for soil nutrients.

4) Risks

The main risk is introducing new weeds if the mulch has been brought from outside of the farm.

(2) Improving the Physical Structure of the Soil by Minimum Tillage

1) Description

Minimum tillage involves reducing cultivation depth and can avoid the use of the plough. It is a tillage method that does not turn the soil over. The approach can involve a number of techniques including direct drilling, broadcasting into existing stubbles or adopting a strategy of reduced tillage.

2) Costs and benefits

Minimum tillage methods can sometimes result in poor crop establishment and increased input costs. For example, there can be an increase in slug activity resulting from increased trash on the soil surface. An increase in grass weeds, can also lead to increased herbicide use. In addition, non-inversion tillage has been associated with increasing the speed of development of resistance to herbicides in weeds and resistance to fungicides in cereal diseases.

The benefits of minimum tillage include:

- Reduced use of labour for tilling and fossil fuels where tractors are used to plough
- Reduced soil erosion in some circumstances
- Potential to increase soil biodiversity, e.g. improved habitat for beetles
- Reduced pesticide and nitrogen leaching in some circumstances, e.g. by virtue of increased organic matter
- Reduced soil compaction

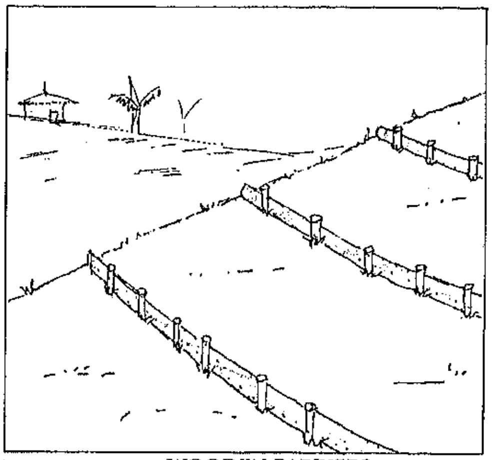
(3) Using Structures to Prevent Soil Erosion

1) Description

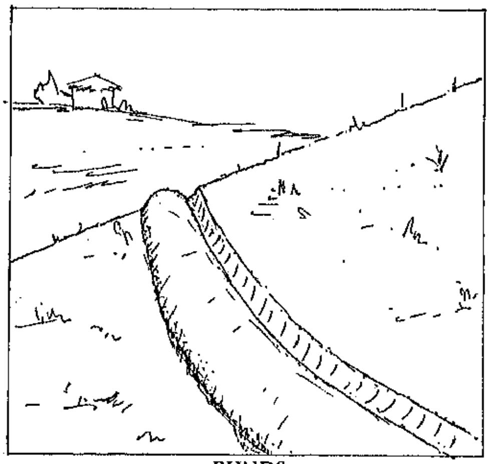
On uncovered sloping ground where soil erosion is more likely to occur it is necessary to construct structures to reduce the speed of the water as it flows down the slope. The more common soil erosion mitigation structures are:

- bench terraces
- wooden barriers
- stone walls
- bunds
- trenches

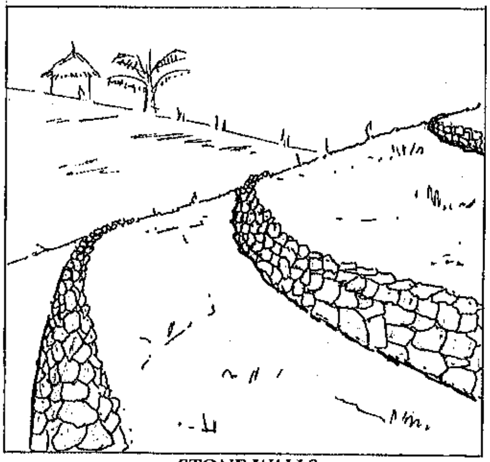
Figure 3.2: Structures to Prevent Soil Erosion



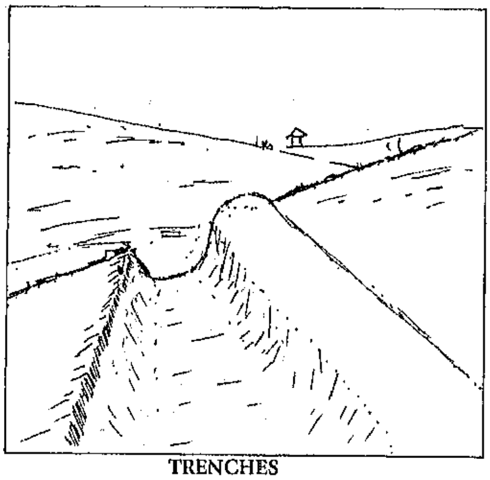
WOODEN BARRIERS



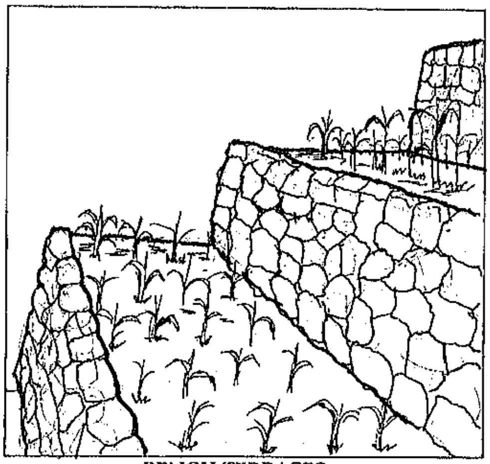
BUNDS



STONE WALLS



TRENCHES



BENCH TERRACES

FANYA JUU / FANYA CHINI

Fanya juu is a structure used in Kenya where the soil removed from a ditch dug accross the slope to catch runoff is placed upslope. Fanya chini places soil downslope of the ditch.

3.3 Desertification

1) Description

Desertification is the transformation of arable or habitable land to desert, as by a change in climate or destructive land use. It is a process by which susceptible areas lose their productive capacity due to land degradation which leads to food insecurity and poverty. Desertification therefore essentially means land degradation in arid, semi-arid and dry sub-humid areas resulting from various factors, including climatic variations and human activities. Note that while land degradation occurs everywhere, it is only defined as "desertification" when it occurs in drylands.

Desertification is accelerated by:

- soil erosion caused by wind and/or water;
- deterioration of the physical, chemical and biological or economic properties of soil;
- long-term loss of natural vegetation through burning and tree-felling for fuel-wood and timber.

Africa, with a rate of disappearance of forest cover of 3.7 to 5 million ha per year reducing substantially surface and groundwater resources and with half the continent's farmland suffering from soil degradation and erosion, is under the greatest desertification threat.

2) Procedure

Combating desertification includes activities that are part of the integrated development of land in arid, semi-arid and dry sub-humid areas for sustainable development which are aimed at:

- prevention and/or reduction of land degradation;
- rehabilitation of partly degraded land through tree-planting, construction of gabions etc; and
- reclamation of desertified land through tree-planting etc.

Local communities play a key role in formulating and carrying out action programmes to combat desertification since they are the ones that depend on and understand the land. National governments have an obligation to provide an enabling environment by removing obstacles and providing support to the implementation of appropriate programmes. This requires strong international co-operation between developed and developing countries.

3) Costs and benefits

The costs of implementing desertification prevention or rehabilitation measures are high. The community has to be organized in such a manner that all must participate in these efforts. Community labour must be provided by all and penalties should be designed for those who do not give the stipulated contribution in labour or materials. However, the community has first to agree on which measures are necessary and affordable.

The benefits of having an active desertification prevention and rehabilitation programme is increase of farmers' yields and a better standard of living.

CHAPTER 4:

FARMING SYSTEMS AND CROPPING PATTERNS

4.1 Overview

Each individual farm has its own specific characteristics, which arise from variations in resource endowments and family circumstances. The household, its resources, and the resource flows and interactions at this individual farm level are together referred to as a farm system. A farming system is defined as a population of individual farm systems that have broadly similar resource bases, enterprise patterns, household livelihoods and constraints, and for which similar development strategies and interventions would be appropriate.

The classification of the farming systems, as specified herein, has been based on a number of key factors, including: (i) the available natural resource base; (ii) the dominant pattern of farm activities and household livelihoods, including relationship to markets; and (iii) the intensity of production activities. These criteria were applied to each of the six main regions of the developing world. The exercise resulted in the identification of 72 farming systems with an average agricultural population of about 40 million inhabitants. Based on these criteria, eight broad categories of farming systems have been distinguished:

- Irrigated farming systems, embracing a broad range of food and cash crop production;
- Wetland rice-based farming systems, dependent upon seasonal rains supplemented by irrigation;
- Rain-fed farming systems in humid areas, characterized by specific dominant crops or mixed crop-livestock systems;
- Rain-fed farming systems in steep and highland areas, which are often mixed crop-livestock systems;
- Rain-fed farming systems in dry or cold low potential areas, with mixed crop-livestock and pastoral systems merging into systems with very low current productivity or potential because of extreme aridity or cold;
- Dualistic (mixed large commercial and small holders) farming systems, across a variety of ecologies and with diverse production patterns;
- Coastal artisanal fishing systems, which often incorporate mixed farming elements; and
- Urban based farming systems, typically focused on horticultural and livestock production.

4.2 Cropping Pattern

Cropping pattern refers to the calendar and intensity of the planted crop. For a farmer, a major objective of adopting a particular cropping pattern is to maximize the amount his family has to live on. But this is only one of the farmer's interests. He may also want his children to be educated; as a result, they may not be available to work full time in the fields. He may also value his time away from the fields: a farmer will not therefore adopt a cropping pattern, however remunerative, that requires him to work ten hours a day 365 days a year. Taste preference may lead a farmer to continue to grow a traditional variety of rice for home consumption even though a new, high-yielding variety might increase his family income. A farmer may wish to avoid risk, and so may plan his cropping pattern to limit the risk of crop failure to an acceptable level or to reduce the risk of his depending solely on the market for the food grains his family will consume. As a result, although he may be able to increase his income over time if he grows cotton instead of wheat or maize, he would rather continue growing food grains to forestall the possibility that in any one year the cotton crop might fail or that food grains might be available for purchase in the market only at a very high price. All these considerations affect a farmer's choice of what to plant, when to plant and how to plant i.e. the cropping pattern, and thus the income-generating capacity of the farming activity.

The way the crops follow each other and the way they are arranged on the farm affect the farm enterprise in many ways: how much labour is required each month, what inputs are required, what is the best time to harvest so as to obtain the best price and so on. This cropping plan also affects the rates of pest infestation and disease infection. For example, the general effects of cropping pattern on pests are:

Staggered planting

- Favours all pests except weeds and nematodes
- Favours biological control
- Pests from maturing fields move to younger fields

Synchronous planting

- Helps with management of rice bugs and other pests
- Is an effective cultural control method
- Can be problematic to achieve where water supply is variable or poorly controlled

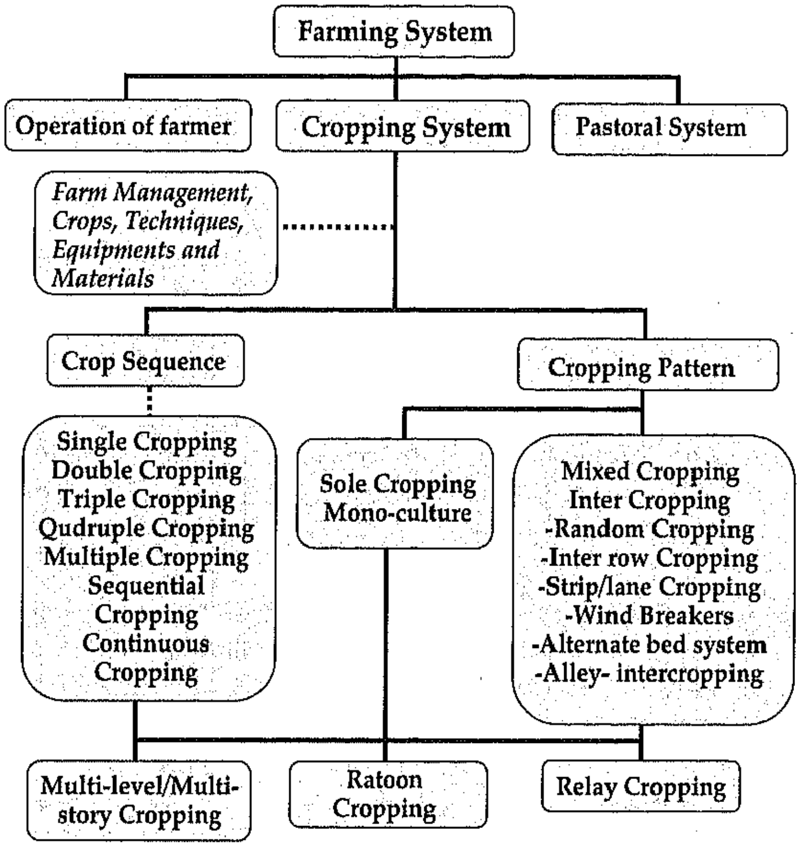
Multiple mono-cropping

- Increases pest incidence and the population of bio-control agents

- Proper pesticide protocols must be followed to conserve bio-control agents. Early applications in particular are problematic as they tend to result in disproportionate increases in pests.

Figure 4.1 shows the relationships between farming systems and cropping patterns.

Figure 4.1: Farming systems and Cropping Patterns



4.3 How to Rotate Crops

The current consensus is that crop rotation increases yield and profit. At times, an increase in nitrogen from legumes in the rotation is primarily responsible for the yield increase; at other times, the decrease in pest pressure has a major positive effect.

Over the years, there has been a significant shift away from extended, or long-term, crop rotations, which include grass, pasture, or hay. The vast majority of maize land is grown in a short-term rotation with beans. In SSA, these are sometimes intercropped, a practice that has been used for hundreds of years with good results.

If one crop is planted on the same field year after year, the pests, diseases and weeds that attack that crop may multiply. Instead, try to grow a different crop each season: for example, plant beans in a field where you planted maize the previous season. This will reduce the number of pests and diseases, since most do not attack different types of crops.

Extended rotations that include grass, pasture, or hay crops can dramatically reduce soil erosion when compared to continuous monoculture. But short-term rotations can actually increase soil erosion when compared to continuous maize.

If you don't rotate crops in your vegetable garden, you risk a build-up of pathogens and pests that will only worsen from year to year. In the case of tomatoes, for example, diseases that build up continuously in the soil can also afflict other members of the Solanaceae family like potatoes and eggplant.

If you commonly grow four crops, divide your available garden space into four plots. If two of the spaces are devoted to tomatoes and cucumbers, plant the remaining spaces with unrelated crops, perhaps lettuce and cabbage in one and carrots in the other.

Then rotate your vegetable plantings each season so that there will be three years before the same crop goes in the same soil. This will help in maintaining nutrient balance in your soil and to ensure your plants are receiving the correct nutrients.
If you have three plots, design your rotation using the example given below.

Crop rotation procedure
Plants are divided into three categories:

- heavy feeders,
- light feeders, and
- soil builders.

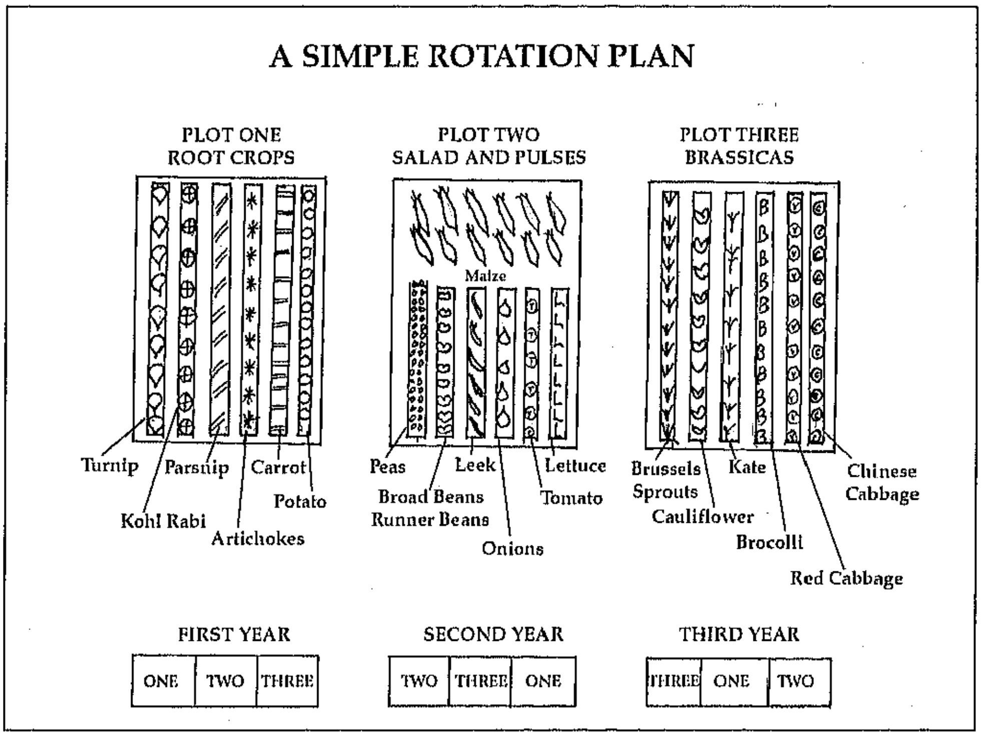
As you plan your rotations, follow heavy feeders by light feeders the second season and by soil builders the third. Or, follow heavy feeders by soil builders and then by light feeders the third season. Try never to have heavy feeder following light feeders.

Heavy Feeders:
Asparagus, Broccoli, Brussels Sprouts, Cabbage, Cauliflower, Celery, Collards, Maize, Cucumbers, Eggplant, Kale, Lettuce, Okra, Parsley, Pumpkins, Radishes, Spinach, Squash, Tomatoes.

Light Feeders:
Carrots, Garlic, Leeks, Mustard, Onions, Parsnips, Potatoes, Sweet Potatoes, Turnips.

Soil Builders:
Lucerne, Broad Beans, Clover, Lima Beans, Peanuts, Peas, Snap Beans, Soybeans.

Figure 4.2: A Crop Rotation Plan



The general rules for crop rotation may be summarized as follows:

- Always rotate the crops you are planting each year. You should never plant the same crop in the same position two years in a row.
- Root crops should never be planted in the same position for two successive years, rather plant root crops the year after planting cauliflower, cabbage or sprouts, as these crops require a rich soil.

- Peas and beans produce nitrogen from the soil, so the following year plant leafy vegetables such as kale or lettuce as these crops require plenty of nitrogen.
- Plant peas and beans to build up the nitrogen in the soil, following root crops which require plenty of nitrogen and may leave the soil depleted. The peas and beans will replenish the nitrogen removed by the root crop.

4.4 How to Use Leguminous crops to Improve Soil Fertility

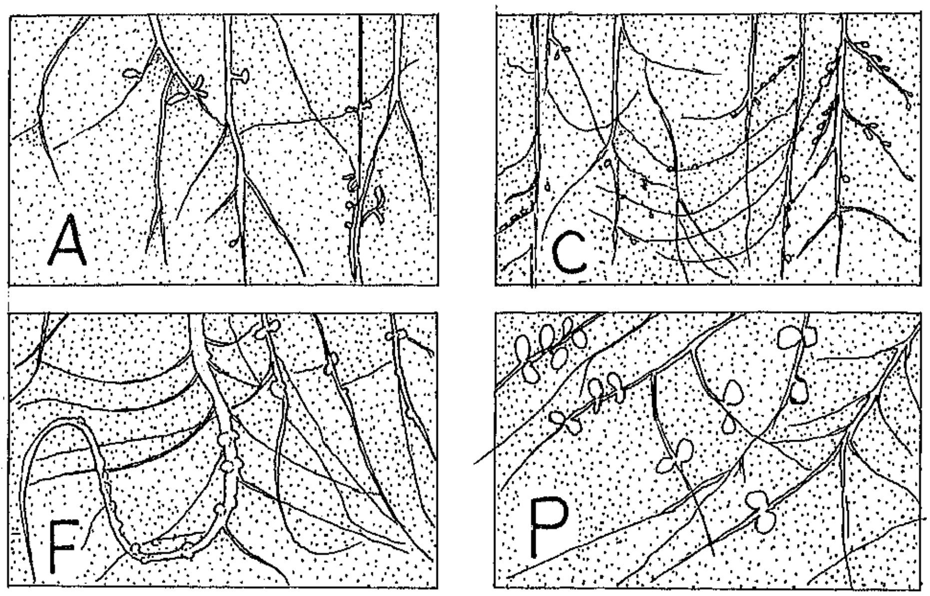
(1) What are Legumes?

Legumes are plants that bear their seeds in pods. They differ markedly from grasses, cereals and other non-legume crops because much of the nitrogen they require is produced through fixation of atmospheric nitrogen by bacteria in nodules on their roots. As a result, legumes are rich in protein. World-wide more than 16,000 species of legumes are known, including herbs, shrubs and trees, but only about 200 are cultivated.

(2) Biological Nitrogen Fixation

Research has shown that the biological nitrogen fixation process is the most efficient way to supply the large amounts of nitrogen needed by legumes to produce high-yielding crops with a high protein content. For the fixation process to occur, legume plants must enter into a "symbiotic" or mutually beneficial partnership with certain bacteria called rhizobia. Soon after legume seeds germinate, rhizobia present in the soil or added as seed inoculum invade the root hairs and move through an infection thread toward the root. The bacteria multiply rapidly in the root, causing the swelling of root cells to form nodules (Figure 4.3).

Figure 4.3 Active Nodules on roots of Alfalfa (A) or Lucerne, Red Clover (C), Fababean (F) and Pea (P)



Source: Microbiology Laboratory, Agriculture Canada Research Station

Nitrogen in the air of soil pores around the nodules is "fixed" by binding it to other elements, and thus, changing it into a plant available form. Some of the carbohydrates manufactured by the plant via photosynthesis are transported to the nodules where they are used as a source of energy by the rhizobia. The rhizobia also use some of the carbohydrates as a source of hydrogen in the conversion of atmospheric N (N_2) to ammonia (NH_3).

The amount of nitrogen fixed varies according to the legume species and variety. Within a species, the amount of nitrogen is directly related to (dry matter) yield. Most grain legumes can obtain between 50 and 80% of their total nitrogen requirements through biological fixation, but some, like fababean will fix up to 90%.

Nitrogen fixation is also affected by the level of available N in the soil. High soil N levels reduce N fixation because legumes will preferentially use most of the available soil N before they begin to fix atmospheric N.

Conversely, soil N levels that are too low can also reduce plant growth. It takes approximately a month from the time of seedling emergence (or the onset of forage legume regrowth) for the nodules to form on the legume roots and begin fixing nitrogen. During this period the legume requires about 15 kg/ha of N, depending on growing conditions, from other sources. Usually, this much residual soil N will be available. If not, addition of a small amount (20 to 30 kg/ha) of N fertilizer placed away from the seed, may be effective. Recent research has shown starter N to be ineffective in increasing yield.

(3) Effect of Legumes on Soil Quality

Legumes have long been recognized and valued as "soil building" crops. Growing legumes improves soil quality through their beneficial effects on soil biological, chemical and physical conditions. When properly managed, legumes will:

- enhance the N-supplying power of soils
- increase the soil reserves of organic matter
- stimulate soil biological activity
- improve soil structure
- reduce soil erosion by wind and water
- increase soil aeration
- improve soil water-holding capacity
- make the soil easier to till

The extent of these soil improvements depends mainly on the type of legume used, the quantity of plant material returned to the soil, and the soil and climate conditions.

Annual grain legumes (pulse crops) generally have smaller and shorter-lived effects on soil quality than perennial forage legumes. The amounts of nitrogen fixed by grain legumes and their influence on soil physical conditions are limited by their typically small and shallow root system and short growth period.

Forage legumes are much more effective in improving soil quality because of their large and deep root system, longer growth period and greater capacity for nitrogen fixation. In the wetter areas, biennial and perennial forage legumes can produce large quantities of organic matter and nitrogen in the second year after under-seeding in cereals. For maximum soils improvement, forage legumes should be managed as green manure with the entire growth being turned under prior to full bloom.

When top growth is harvested for hay or silage and only the stubble is turned under, less than one-third of the legume dry matter and nitrogen is retained by the soil. However, even when legumes are used for hay or silage, the beneficial effects on soil quality and following crops may be substantial.

On degraded soils with typically low organic matter contents, regular green manuring with forage legumes increases soil nitrogen and organic matter over extended periods. The main effect of turning under forage legumes as green manure is to add nitrogen-rich, readily decomposable plant material to the small mineralizable portion of soil organic matter. However, turning under fresh legumes also greatly stimulates the activity of soil microbes and, as a result, speeds up the cycling of nutrients.

(4) Effect of Legumes on Subsequent Production

Biennial legumes, like sweetclover, can markedly increase grain production. Annual legumes that are capable of fixing large amounts of nitrogen under good moisture conditions, can significantly improve the nitrogen supply for succeeding crops. The yield response of barley to N fertilizer has been shown to be slightly greater on barley than on pulse residues. But fertilizer alone, even at rates up to 180 kg N/ha, was unable to bring barley yields on barley residue up to the maximum yield obtained on pulse residues. This confirms that benefits from use crops are not only due to the added nitrogen they provide to succeeding cereal crops but also to positive `rotational effects' due to disease suppression, improved tilth and other enhancements of soil quality.

(5) Legumes and Green Manuring

Legume green manures offer several advantages over conventional fallow as they tend to improve, enrich and protect the soil. In more drought-prone areas, deep-rooted biennial and perennial legumes are not suitable for green manuring, as their excessive soil moisture depletion will depress the yield of subsequent cereal crops for several years.

Growing annual grain legumes can increase the yield of succeeding crops in the rotation. This benefit, called *rotation effect*, is due to more than an increase in high-N crop residue. For example, a pea crop that yielded 2000 kg seed per ha would produce about 3000 kg of crop residues containing 1% nitrogen, or about 30 kg N/ha, about half of which would be available to the succeeding crop.

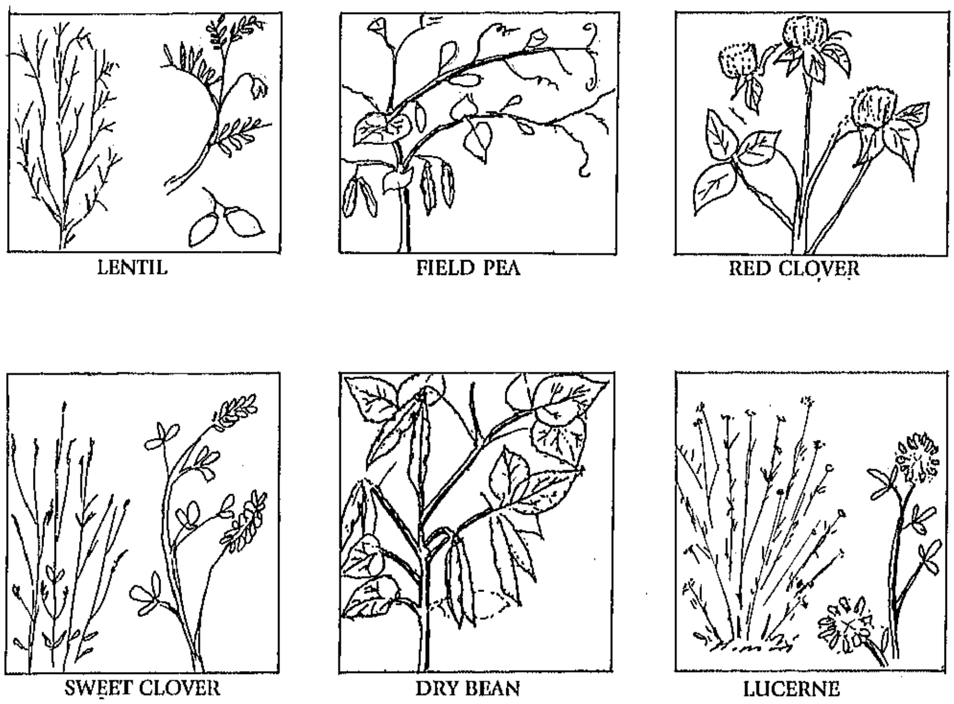
Good soil fertility is required to achieve high yield and protein content. Placing phosphate fertilizer with or near the seed is particularly important due to the "pop up" effect which results in a more vigorous seedling better able to compete with the weeds.

(6) Rotations

Sweetclover fits well into short rotations with grain crops because it is a biennial. It is best adapted to use on problem soils such as degraded soils low in organic matter, soils where crusting is a problem or on saline soils. In many cases it fits well into rotations as a substitute for summer fallow.

A cereal crop should be grown following sweetclover. Oilseeds do not respond as well as cereals when grown immediately after sweetclover. When grown as a second crop after sweetclover, oilseeds frequently show yield responses on degraded, low organic matter soils or those that crust. Figure 4.4 shows examples of common legumes.

Figure 4.4: Examples of common legumes



4.5 Pest and Disease Management through Crop Rotation

One of the major benefits of crop rotation - especially an extended crop rotation using three or more crops - is its age-old capability to maintain crop yields. The inclusion of soyabeans or forage legumes in crop rotations reduces the need for nitrogen (N) fertilizer.

The other benefits of crop rotation include improved weed, insect, and plant disease control, and lower input costs. Using Integrated Pest Management (IPM) may help lower your crop pest management input costs. Crop rotation is part of an IPM strategy designed to manage pest populations. Scouting crops to determine economic thresholds (where you may need to use a pesticide to control a pest population) is another IPM strategy. Implementation of an extended crop rotation of three or more years is particularly helpful in breaking the developmental cycles of pests. Diversifying crops in an extended rotation changes the host plants of potential pests, which in turn disrupts the life cycles of plant diseases, insects and weeds.

CHAPTER 5:

INTEGRATED AGRICULTURE

5.1 Overview

Integrated agriculture is a method between conventional and biological agriculture. The aims are to:

- give nutrients (minerals) to the plants, according to their needs
- use animal manure instead of chemical fertilizer as much as possible
- depend as little as possible on chemical pesticides
- keep a reasonable income for the farmer and his family.

Integrated farm management tries to prevent damages, caused by insects, weeds and diseases by:

- crop rotation: each year the different crops are planted somewhere else, this way some diseases cannot spread easily
- using stronger races or types, that are more resistant against diseases
- quick covering of leaves, to control the weed
- giving low mineral gifts, to strengthen the plants
- measuring nitrogen in the soil and leaf stalk, that way it can be known how much (animal) manure has to be added
- mechanical weed control (by harrowing and weeding)
- only spraying chemical pesticides *in the row*, and not *in between* two rows using thresholds for pest (for example: aphids) control

As much as possible manure and <u>not</u> chemical fertilizers should be used on the farm. This manure should be applied and thoroughly mixed with the soil for higher Nitrogen efficiency.

5.2 Preservation of the Environment

Through integrated agriculture practices, it is possible to preserve open space and farming heritage while improving ecological benefits for wildlife. This concept can be applied two ways: by utilizing agricultural techniques such as grazing to assist in the management of ecological preserves; or by using environmental principles in farming to enhance the farm fields' value as habitat. The Maasai and other cattle keepers of the Horn of Africa have maintained integrated grazing systems that have preserved a suitable environment for game over centuries. The game is now another income-earner for those communities as they collect levies from game camps and hotels, as well as visitors who come to view their game.

Therefore, environmental management of farmland serves many purposes such as preserving open space and farming heritage, producing revenue, and enhancing the usability of the farmland for wildlife habitat.

5.3 Integrated Agriculture and the Various Crops

The future of agriculture lies in sustainable agriculture, which means that farmers will have to:

- have a good income
- have respect for other society interests like drinking water
- have respect for nature and environment
- think of the future generations
- improve the quality of their products

But farmers are to be given some time to realize these changes step by step and every farmer in his own way. And these changes are impossible if society doesn't support the farmers who want to change.

5.4 Agriculture-Fish Integrated Farming Systems

There are many interactions between fisheries and agriculture through the common use of land and water resources and concurrent production activities to support rural village communities and supply urban areas with the needed quantity and variety of food. Such interactions extend to the institutional sphere, as fisheries and agriculture often fall within one government ministry. Improved integration between the two sectors is therefore an important means for enhancing fish production and food security.

The overall objective of integrated agriculture-aquaculture (IAA) is to maximize the synergistic and minimize the antagonistic interactions between the agriculture and the fisheries/aquaculture sectors. The most direct antagonistic interactions between agriculture and fisheries occur where these two sectors compete for land and water, and where measures aimed at higher agricultural production can alter fish habitats and fish stocks.

Agriculture and aquaculture offer a large variety of cropping patterns under different climatic and soil conditions. The possibilities for integrating fish farming into irrigation systems are growing as they prove beneficial. Such benefits have been seen with the African network and with the use of small ponds. Extension and training are crucial for informed decision-making, and physical infrastructure, efficient input markets and credit facilities are indispensable for the optimal development and integration of farming and aquaculture systems.

(1) Integrated grass-fish farming systems

Integrated fish farming systems refer to the production, integrated management and comprehensive use of aquaculture, agriculture and livestock, with an emphasis on aquaculture.

Integrated fish systems, using grass and aquatic plants as fish feeds, are commonly found in many parts of China. These systems are particularly predominant in the irrigated lowland areas of the Changjiang, Pearl and Yangtze River basins. Many of these farms are large, communal ones with cooperative or collective farming. The methods they use can be adapted to smallholder farming in SSA. Three integrated systems from China, involving grass and/or water hyacinth have been adapted for SSA and are presented here: grass-fish, water hyacinth-fish and cattle-grass-fish.

(2) Grass-fish

Grass species, which can easily be produced on the farm, can serve as low-cost supplemental feeds for fish. Fish species, which can feed directly or indirectly on grass include silver, bighead and common carps. As seen in Figure 5.1, grass can be grown along pond boundaries and fed directly to fish. Grass species commonly used include rye, Sudan and napier grasses. Figure 5.2 outlines a seasonal calendar for grass production within a grass-fish system.

Figure 5.1: A grass-fish system

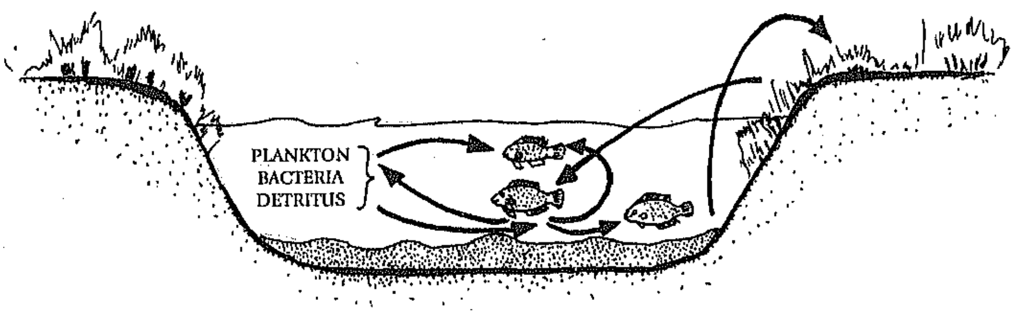
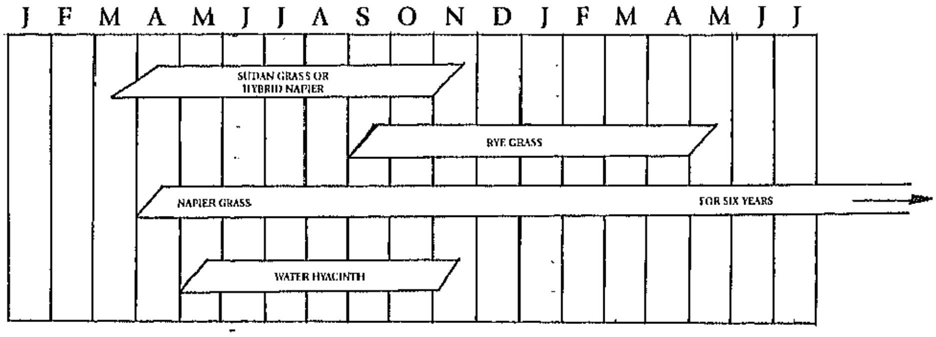


Figure 5.2: Summary of important aquatic and terrestrial species used for grass-fish integration



(3) Water hyacinth-fish

A variety of aquatic plants can be used as supplemental feeds in fish production, among them the water hyacinth. An area approximately a half the size of the fishpond is needed to produce enough water hyacinth for supplemental feeding. Water hyacinth can produce up to 300 t/ha/year (fresh weight). Net fish yields can also reach 6 t/ha/year without supplemental feeding or use of additional manures. Fish input costs using water hyacinth comprise less than 15 percent when compared to cereal grain (barley)-fed fish. Note that in many countries, water hyacinth is banned and has caused serious problems in lakes, rivers and estuaries.

(4) Fodder-fish integration

Integrated fodder-fish systems are technically feasible and economically viable; but socioeconomic factors, such as consumer preference, adoption by farmers, etc., need to be considered before they can be adopted. This system benefits family consumption by providing enough supply of protein. Moreover, it can be a source of additional income.

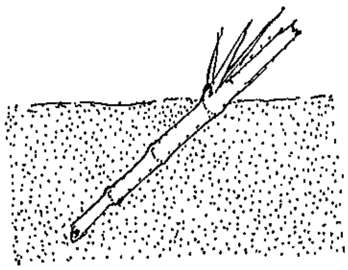
The fodder-fish integration utilizes the most commonly used fodder species as fish feeds. These are: napier grass (*Pennisetum purpureum*), cassava (*Manihot esculenta*) and *Leucaena leucocephala*.

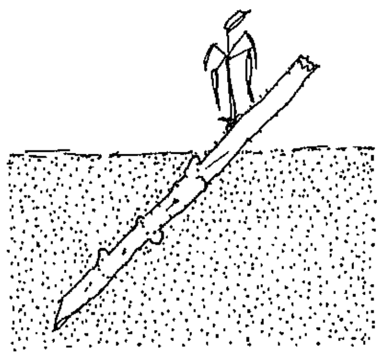
1) Land preparation and planting of fodder crops

a. Weed the land.
b. Plant fodder crops.

- Napier grass and cassava are propagated by vegetative means using mature stems. Napier grass cuttings should have 3-5 nodes, three-fourth of which is buried (at about 45° angle). Cassava planting material is 25-30 cm long.
- Water the crops with manure pond water.

Figure 5.3: (a) Planting napier grass ***b) Planting cassava***





c. Management care

- If possible, put a fence around the area.
- Do not allow grazing of animals.
- Apply fertilizer/compost every month.

d. Harvest the fodder

- Napier: first cutting at 7 cm from the ground (to encourage vegetative growth) 6-8 weeks after planting. Then, cut regularly every 2-4 weeks, 10-15 cm from the ground.
- Cassava: first cutting 0.5 m from the ground, 8 weeks after planting, then regularly after every 4 weeks.
- Legumes: first cutting 8-12 months after planting, then regularly after every 8-12 weeks, 0.3 m from the ground.

e. Feed preparation

- Leaves of these fodder crops are used as feeds. However, for cassava, the tuber can also be used. The leaves are chopped in small pieces before feeding to hatchlings or fry. For big fish, the leaves are simply placed in the pond.

2) Fish culture system

a. Pond design

The pond (0.1-0.5 ha in size) should be established near a water source and should be free from flood or drought.

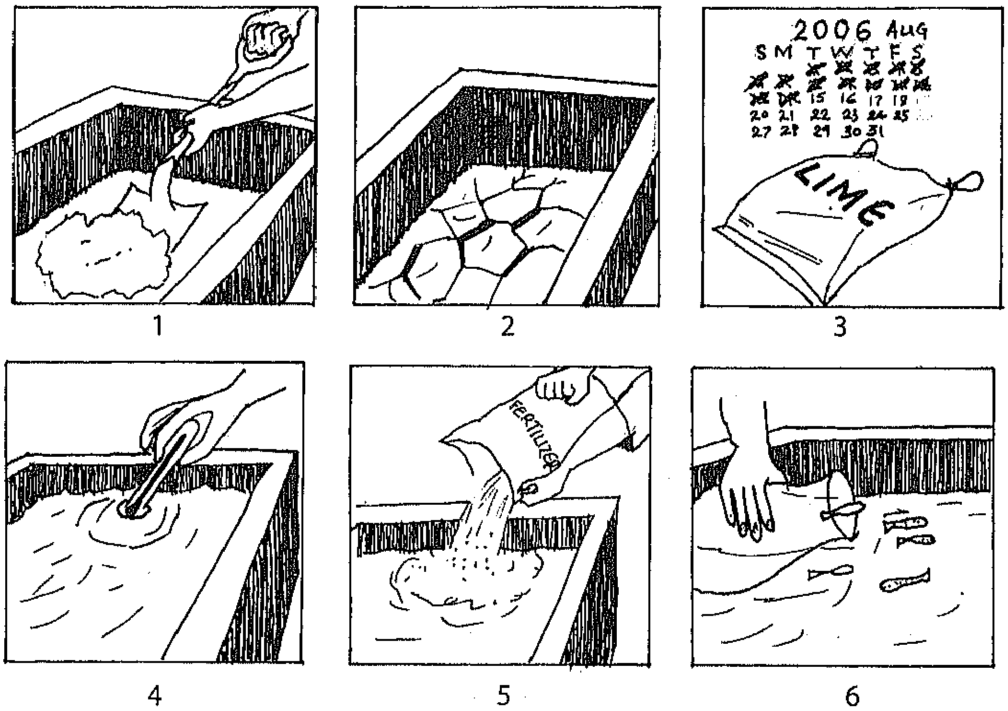
Bunds between 2 m and 3 m wide and at least 1.5 m deep are built to separate the ponds. Water is supplied through gravity flow. Screened inlet and output pipes are installed.

A feeding area within the pond is constructed (located at the side). Bamboo poles or trunks of trees can be used.

There are two types of pond:

- Nursery pond - used for nursing 2.5-7.5 cm fry until the desired size is reached.
- Grow-out pond - bigger than the nursery pond, it is used to raise fish up to marketable size or to grow fish for breeding.

Figure 5.4: Steps in preparing a fish pond as described in b. below



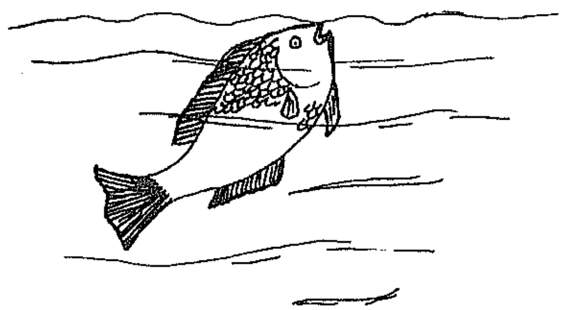
b. Pond preparation and system establishment

1. Drain the pond (if the pond is an old one from which the fish have been harvested). Remove silt on the pond bottoms; this can be used as fertilizer.
2. Dry the pond bottom until the soil cracks. Ploughing it first turns the soil over and facilitates drying.

3. Apply lime to condition the soil. Liming activates fertilizers and controls acidic soils which may harm the fish. Quicklime is most commonly used at 200 kg/ha.
4. Fill the pond with water 2 weeks after liming. Water should fall from the water inlet into the pond below, so that the water mixes with oxygen from the air. Also check water condition:
   - temperature = 22°-32°C
   - early morning oxygen = 3 mg/litre
   - pH = 6.5-8.3
5. Add fertilizer to the pond to provide nutrients for fish and plankton growth. Chicken manure can be applied.
6. Stock the pond, preferably in the evening.

If the fish are at the pond surface, feeds are needed. If they are gasping at the surface or the prawns are in the periphery of the pond, aeration is needed. Aerate the pond by stirring the water with a tree branch. Suspend fertilizer additions and later resume with reduced rates. Also, watch for predators.

Figure 5.5: Fish gulping air on the surface in water that is low in oxygen



c. Feed the fish/prawn

Option 1: After the pond is fertilized, introduce duckweeds. Grass carp feed on duckweeds for the first month. Then, give chopped cassava leaves and napier grass. Feeding is twice a day (morning and afternoon).

Upon transfer into the growout pond, feed the fish with grass and cassava leaves (200 kg/day). For tilapia, cooked maize, food leftovers and chopped cassava are given. The amount depends on the fish behaviour. If the fish are still in the feeding area, more feeds are needed.

Option 2: At the start, feed the fish four times a day. Give rice bran, bread, cassava and napier grass.

For the fish, give feeds inside the feeding area. For the prawn, broadcast the feeds all over the pond. If there are still feeds found in the water, stop feeding.

- Monthly management of fishpond
  - Check the pond walls and bottom. Remove any debris which might be a problem at harvest time, e.g. twigs, leaves, etc.
  - Check the fertility and turbidity of the water by dipping your arm into the water. If the palm disappears before the water reaches the elbow, there is dense algal bloom.
  - Check the fish carefully for any sign of disease.
  - About three to four partial harvests can be done using a sieve net before final harvest. For prawn, harvesting is after 6-7 months and for fish, after 10-12 months. Survival rate is about 70-90 percent for fish and about 30 percent for prawn.

d. Benefits

- Environmentally sound.
- Prawn/fish is of high (economic) value.
- Seed is easily available.
- With polyculture, different water columns are used, minimizing competition for food among different species.
- Acceptable to consumers (as against fish grown in ponds loaded with manure or sewage).
- The fodder crop can last for 5-7 years with minimum maintenance.
- System is open to the introduction of additional components at a later stage.
- Various combinations can be used to get highest yields and incomes.

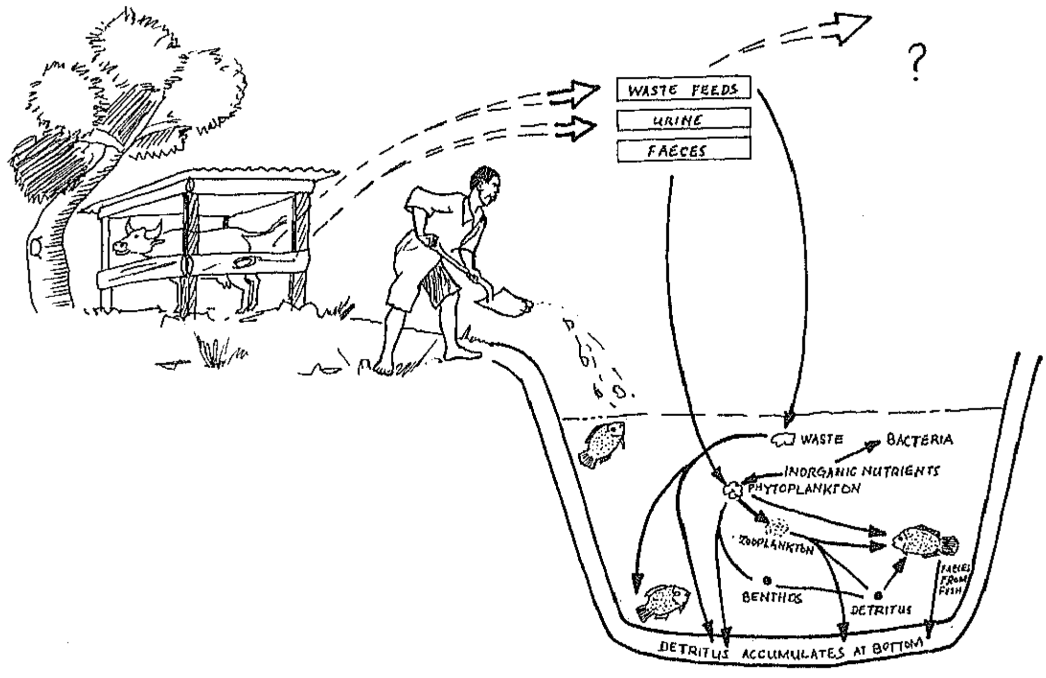
e. Limitations

- Cannot be applied on a large-scale basis.
- Requires high-labour inputs.

(5) Using animal wastes in fishponds

Animal wastes can be used in fish ponds as shown in Figure 5.6.

Figure 5.6: Flow of animal wastes



1) How animal wastes work in a pond

Direct feeding value of pure wastes is known to be poor. Wastes act by:

- stimulating phytoplankton production; and
- acting as media for bacterial production (detritus) and as feed for zooplankton.

2) Factors to consider before using animal wastes

a. Are wastes available on-farm? If so, are the wastes already used? Should they be diverted for use in fish culture? Livestock wastes are often important as crop fertilizers and fuel.

b. Is it worth raising livestock, especially to generate wastes for aquaculture?

Consider:

- costs/difficulties of doing so (e.g. feed availability and cost, marketing difficulties, technical abilities and interest of farmers).

3) Management factors to consider

a. Are all wastes to be used in fish culture?
If wastes are to be used elsewhere, they should be collectible prior to entering the pond (e.g. use a sump). Also, wastes should be available in larger quantities at certain periods when their use should be reduced for fish culture (e.g. during the cool season).

b. Can all wastes be collected?
Feedlot livestock are kept confined at all times so all the wastes can be collected and used.

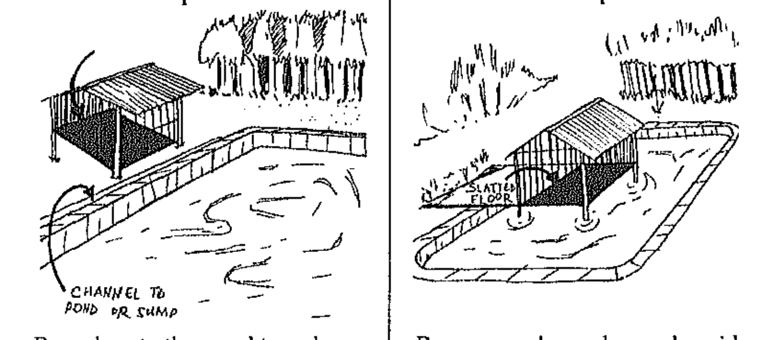
Small-scale farmers often allow livestock to graze or scavenge during the day and only confine these at night. This reduces feed costs considerably, often allowing only on-farm or low-cost, supplementary feeds to be given. However, collectible wastes will be less.

c. Livestock may be penned at the farmer's house for security or traditional reasons; this may limit potential advantages of integration. Labour is required to collect or prepare livestock feed.

d. Ponds may be multifunctional. Large animals are usually denied access to the pond because entry to and wallowing in it can destroy the dikes and cause turbidity which reduces natural food production. Figure 5.7 shows the two options of building an animal shed for ease of using the animal wastes in the fish pond.

Figure 5.7: Design the pond to allow limited access and place animal shed close (a) or above (b) it

On the pond dike | Over the pond

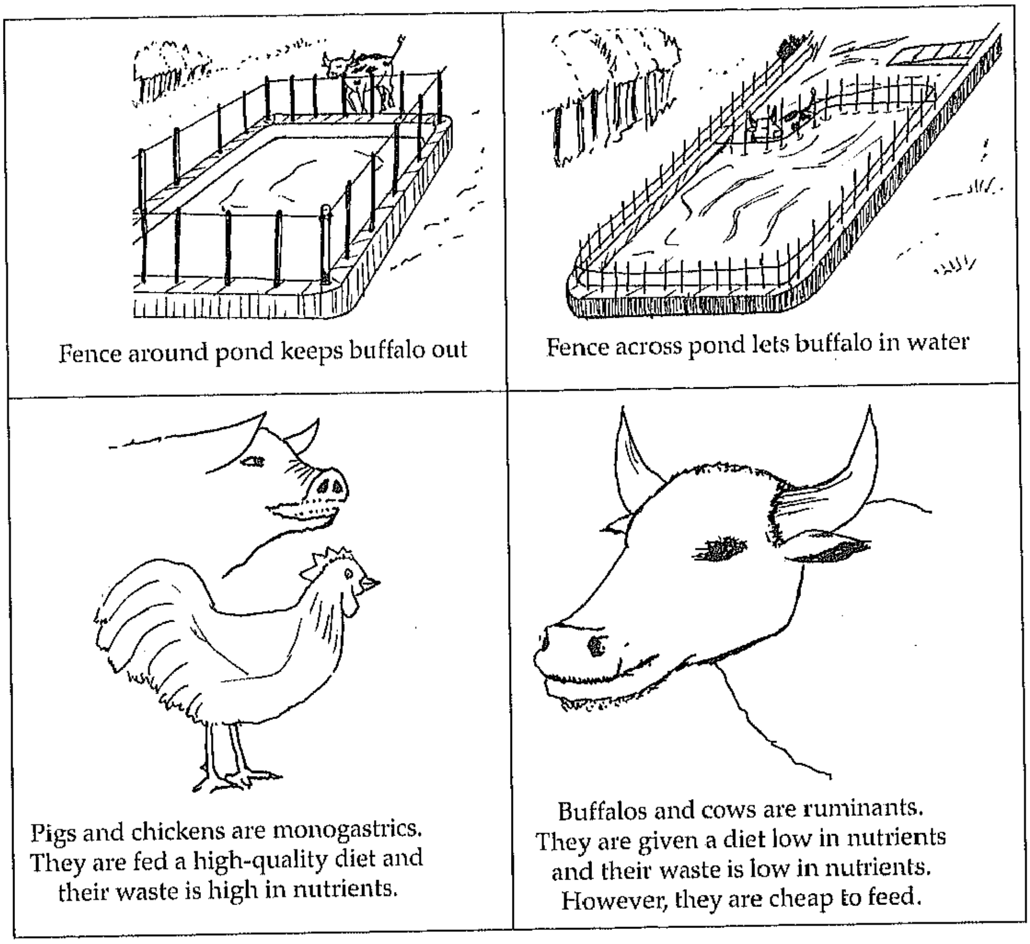


Pens close to the pond to reduce labour cost of loading waste (a)

Pens are cooler and more humid (b)

In the layout/design aspect, consider:
- size and number of livestock;
- space availability/land cost; and
- relative cost of materials.

Figure 5.8: Pond plans and fish food sources



Fence around pond keeps buffalo out

Fence across pond lets buffalo in water

Pigs and chickens are monogastrics. They are fed a high-quality diet and their waste is high in nutrients.

Buffalos and cows are ruminants. They are given a diet low in nutrients and their waste is low in nutrients. However, they are cheap to feed.

Other important facts:

- Young livestock tend to feed on diets higher in protein so their waste has more nitrogen and is better as a pond input.
- Ruminants' faeces/droppings contain high levels of carbon relative to nitrogen and discolour the water. Generally used alone, they give low-fish yields. Consider use of ruminants' urine as it contains a better balance of nutrients.
- Laying hens are fed different diets from broiler chickens and their waste is particularly high in phosphorus.

4) Tips for proper waste application

- First application can be done about 1-2 weeks before fish stocking to produce natural food for immediate fish consumption.

- Apply or load manure after sunrise (about mid-morning).
- Maintain a regular schedule or routine of application.
- Make sure that freshwater is available for flushing in case of direct oxygen depletion.
- Scrape off 2-5 cm of the pond bottom soil during pond preparation. This can serve as an excellent fertilizer for vegetables.

5) Water quality management

Too much manure when loaded in fishponds can cause dissolved oxygen depletion resulting in fish mortalities. When manure loading is excessively high, too much decomposition occurs; thus, the biological oxygen demand is high, using up the available dissolved oxygen.

Phytoplankton produces dissolved oxygen during the day but consumes it at night. Another source of dissolved oxygen in static water is diffusion of atmospheric oxygen.

6) Indicators of low dissolved oxygen

a. When plenty of fish are on the water surface 'gasping for air' (i.e. they are consuming oxygen from the thin and oxygenated top layer of water)
b. When air or gas bubbles are observed in the water
c. When the pond water is brownish or greyish
d. When the pond water smells pungent.

7) What to do when dissolved oxygen is low

- Stop loading manure.
- Add freshwater into the pond while draining water off the pond bottom.
- Stir the pond water by striking the water surface with tree branches or other appropriate materials; row repeatedly across the pond.
- Make provisions for flow- through system (if water is readily available).
- Use mechanical aerators (if available).

If the water is turbid because of suspended sedimentary particles, spread over the pond surface chopped rice straw or hay, allowing them to settle at the pond bottom together with the silt. But caution: too much decomposing hay can also deplete dissolved oxygen. The pH or hydrogen ion concentration determines whether the water is acidic or alkaline. Highly acidic water (pH 4 or below) can result in fish death.

(6) Biogas slurry in fish culture

Cow dung is commonly used as a fertilizer for fishponds but fish production is limited to 1500-2000 kg/ha. These yields can, however, be more than doubled if the dung is first fed to a biogas plant and the digested slurry then used instead of the raw dung. The following methodology for a 0.4 ha pond exemplifies the technology.

a. Prepare the pond using the urea-bleaching powder method or by draining-dry.
b. Stock the pond with 2000 (5- 8 g) fingerlings of carps e.g. catla, 20; rohu, 25; silver carp, 20; grass carp, 5; and common carp, 10.
c. Fertilize the pond daily with 30 litres of biogas slurry. The slurry is rich in nitrogen and phosphorus, and is free from toxic gases which are produced when cow dung decomposes in ponds.

Excess slurry is used for the field while the gas is used both in the kitchen and for lighting the house. The slurry is not applied on a cloudy day or when the fish come to the surface to gulp air.

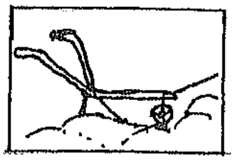
d. Surface feeders will have reached about 1 kg individual body weight in 6 months. All marketable fish are then harvested every 2 months and replenished with an equal number of fingerlings. A total of 2000 kg of fish is obtained using biogas slurry as against 800 kg if raw cow dung is used.

(7) Fingerling production in irrigated paddy

Supply of fish fingerlings is scarce and usually expensive in SSA. It is also tedious for fish farmers to procure fish seeds. An alternative is the production of common carp (*Cyprinus carpio*) fingerlings in different types of irrigated paddy. Although production figures are below the commercial rates, small farmers can grow their own fingerlings at minimal cost. Figure 5.8 illustrates the calendar of operations in fingerling production in a paddy field.

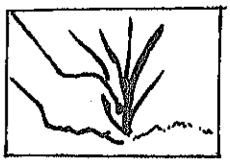
Figure 5.9: Calendar of activities in fish production

DAY 1



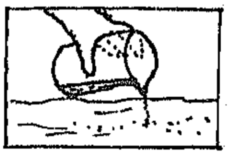
Prepare paddy field.

7



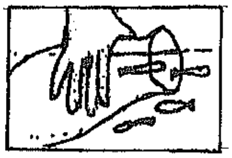
Transplant rice.

10



Apply approved chemical to kill predators.

11

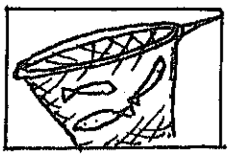


Stock with 2-week old fingerlings at $10/m^2$.

18

Monitor fingerling growth by weighing every week. Maintain water depth at 7-10 cm in the paddy.

53



Harvest the fingerlings. Condition them before selling or stock them for futher growth.

Benefits

a. Fish hatchlings or fry can be reared in different types of paddy plot designs without altering the farmer's normal practices in rice production.
b. Farmers' existing resources can be used.
c. Only minimum additional expenses are required.
d. When the fish get bigger than 2.5 cm, they control weeds, pests and insects in the paddy
e. Fish droppings serve as fertilizer for rice.
f. Additional income can be provided.
g. Farmers can sell fingerlings when prices are highest.

What to consider before adopting the technology

a. Paddy soil should have good water-holding capacity.
b. Although tilapia can be stocked, common carp is recommended for stocking for these reasons:
   - it spawns earlier;
   - fry are available at the same time as paddy rice transplantation; and
   - it is a hardy fish.
c. Fish have higher survival rates in smaller paddies.
d. If possible, use fry (instead of hatchlings) for stocking because they have higher survival rates.
e. Use of supplementary feed, like rice bran or wheat bran, can help increase fingerling production at minimum cost.
f. To reduce risks of paddy field drying out, replenish water to the desired levels frequently.

5.5 Considerations in introducing integrated Agriculture-Aquaculture Technology

(1) Socio-cultural considerations

It is important to know how farmers understand the world before trying to introduce new technological options. Explore whether or not the new system can fit in well with the farmer's concerns, beliefs and values. Remember farmers are also "scientists" and they know what works for them and what does not. They have been developing, testing and adopting their own technologies for centuries in ways that are tailored to their cultural setting. If you first make effort to learn from them about the fit between cultural outlook and technology, then you will have a much better idea of which new technologies they are likely to take an interest in.

Some general considerations

- Agricultural scientists and economists value replicability of results, as well as maximizing efficiency and profitability.
- Farmers may be motivated by goals and values that favour them.
- Farmers may value security of livelihood for themselves and their children in the short and long term. They place a higher priority on preserving harmony in the community than on maximizing individual gain.
- Women may not be permitted to catch fish, but they may be the ones who sell them.
- It may be unacceptable for male extension workers to speak freely with women. Or a young extension worker may feel uncomfortable giving instructions to a distinguished community elder.

- Children may aspire to enter non-farm occupations or may be less concerned with respecting religious taboos.
- Muslims will not eat pig meat or fish raised with pigdroppings; many will not consume shellfish, but this depends on local custom and preferences.
- Especially in Africa, but also among tribal peoples in Asia, Melanesia and the Americas, some people are forbidden to eat the animal that stands for their clan group.
- In some societies, men may be allowed to eat certain foods that are forbidden to women and vice versa. Often, men expect to be given the most nutritious and preferred foods first. These factors may reduce the nutritional benefits that women receive from fish or livestock production. On the other hand, sometimes women can demand these foods when they are pregnant or nursing.
- Sometimes people believe that certain foods are unclean or will make them sick. For example, many people refuse to eat fish raised on animal excreta.

(2) Economic considerations

How to make your farm budget:

First, make a *cost sheet.*
- List the things that are required for you to use the technology.
- Write down how much is needed, its price and the amount paid.
- Add all amounts paid to find out the total costs.

Second, make an *income sheet.*
- List all the products from the technology that were sold.
- Write down how much is sold, at what price and the amount received.
- Add all amounts received to find out the total income.

Third, work out your *balance or profit sheet.*
- Write down the total income received from the technology.
- Write down the total costs that were required in applying the technology.
- Subtract the total amount paid for you to use the technology from the total amount received from the sales of the technology.

Fourth, analyse the *risks and market*
- Is the produce from the technology meant for household and local consumption or for export?

- How diversified will the farm operations become when the new component technology is adopted? Will it increase/reduce risks in crop failure?
- Will the products of new technology be subjected to high degree of price uncertainty because of unstable market?
- How sensitive is the net return to changes in input costs and output prices?

Fifth, analyse the *equity/income distribution*

- Is the new technology going to place significant demand for labour time from family members?
- Who will meet such labour demand?
- What is the opportunity cost of additional labour hours in terms of leisure, children's schooling, household work by female labour force, etc.?
- Is the technology attractive as an income earner?

CHAPTER 6:

IRRIGATION

6.1 Overview

(1) Water as a Scarce Agricultural Resource

This chapter explains procedures to use simple sustainable irrigation techniques that save water while at the same time giving the farmer the food production outcomes worth of his labour, and conserving the environment.

Fresh water is becoming an ever increasingly precious commodity, control of which could lead in the near future to major prolonged conflicts. At the village level, for instance, there are many cases of conflict caused by shortage of water and water stealing has become a major problem in irrigated areas in SSA.

(2) Irrigation in Africa

Total irrigated land in Africa is estimated to be about 12.2 million ha. This figure includes all land where water is supplied for the purpose of crop production, excluding only areas where water harvesting and spate irrigation are practiced. Irrigated land represents, on average, less than 8% of the arable land, with large differences between countries.

(3) Improving Efficiency of water Use

The availability of water varies tremendously by region, and in some regions it is exceedingly scarce. Even in areas with limited water supplies, however, irrigation can vastly increase agricultural productivity and is crucial to improving food security.

Underused water resources in parts of Africa offer great potential for irrigation, especially using simple and inexpensive technologies. Africa uses less than 6% of its renewable water resources, compared with 20% in Asia. Further, only 7% of the arable land in Africa is irrigated, compared with 38% in Asia.

Small-scale water harnessing, irrigation and drainage works carried out at the rural community level using local labour offer an effective and low-cost option for improved water control. Such solutions should be simple, and should involve small changes to the way things are done. Water harvesting – collecting water in structures ranging from furrows to small dams – allows farmers to conserve rainwater and direct it to crops.

Large-scale public irrigation schemes have been found to be complex and difficult to manage though they have contributed to poverty alleviation and boosted agricultural production in Asia, the Near East and parts of Latin America. In SSA, many such schemes have failed due to limitations of resources to ensure proper operation and maintenance of infrastructure, and difficulties in effectively marketing produce.

(4) Sources of Irrigation Water

The major sources of irrigation water are rain, rivers, streams, fresh water lakes, shallow wells and boreholes. Water for irrigation has to have the desired level of mineral content so that it is neither too acid nor too alkaline. Its pH should be close to neutral i.e. pH 7.0, although various crops have different tolerances to different levels of acidity and alkalinity. When water has the right characteristics that do not harm the crop being irrigated, it is said to be suitable for irrigation. Where possible, water can be tested for acidity/alkalinity with simple paper strips that change colour when immersed in water.

6.2 Water Abstraction from a River or Stream

1) Description

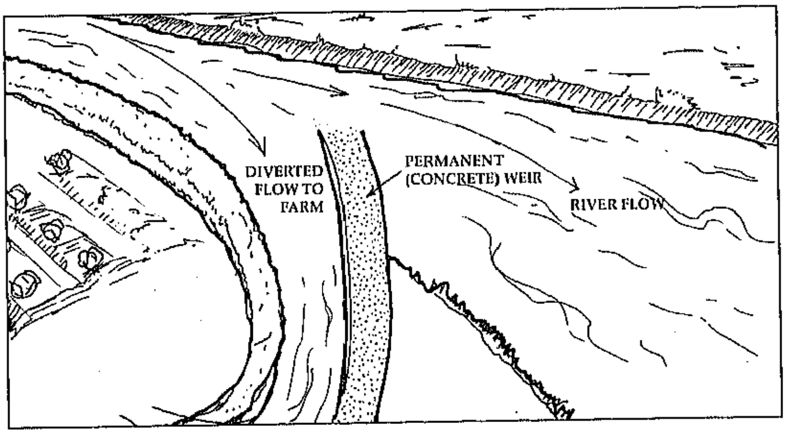
Once water is found to be suitable for irrigation, it is abstracted from its normal course (river, stream), pumped out and lifted to the level of the farmland (well, borehole, lake) or harvested using structures and led to a reservoir or channel that conveys it to farmland (rainwater runoff).

Water from a river/stream is abstracted using a diversion structure called a weir. A weir is a permanent or temporary structure built across a flowing stream to raise its level so that water can be led into another channel.

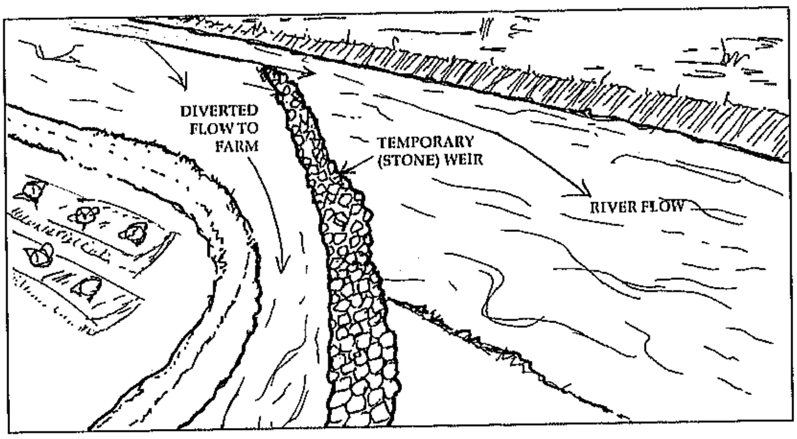
2) Procedure

Find a suitable point where the stream is narrow and the banks are low. Check to see that water can flow towards the area identified for irrigation. Dig a furrow to convey water to the land to be irrigated. Place stones, logs or sand bags across the stream to raise the level of the water (Figure 6.1). Lead the water into the furrow to the irrigated land. A permanent weir is made of concrete.

Figure 6.1: ***(a) A permanent weir***



(b) A temporary weir



3) Costs and Benefits

A temporary weir can be made by the community if the water is intended for a village irrigation scheme or by one farmer if the water is for individual use. Labour is provided by the villagers themselves, stones are collected in the locality and sandbags are made by the villagers. The extension officer should be able to decide where the weir should be placed and where the furrow should follow using simple instruments to check the level of the land. The benefits are that water will flow continuously to the irrigated land.

4) Risks

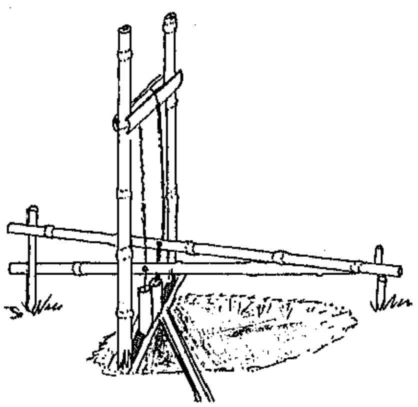
Temporary weirs are easily washed away when the river rises as a result of rains. However, this is the time when irrigation water may not be needed. To avoid repeated reconstruction, a weir should be reinforced with logs and the river should be allowed to flow over or beside it.

6.3 Pumping Water from a Well, Borehole or Surface Sources

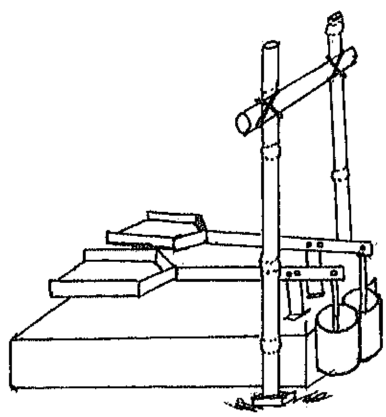
1) Description

Water from a shallow well should be raised to an overhead tank or be directed to the field using a treadle pump (TP) or other suitable low-cost pump. The treadle pump (Figure 6.2) originated in Bangladesh in the early 1980s. The pedal pump (MoneyMaker brand) used in Eastern Africa is a lighter and more portable adaptation of the Asian treadle pump by a local NGO (Approtech). There are three models of it sold in Eastern Africa (Figure 6.3). It is actively marketed in towns and villages. The pump is most appropriate for smaller, subsistence farmers and market gardeners who see the opportunity to expand irrigation on small plots by 50 percent more than their existing irrigated area.

Figure 6.2: Two types of treadle pump

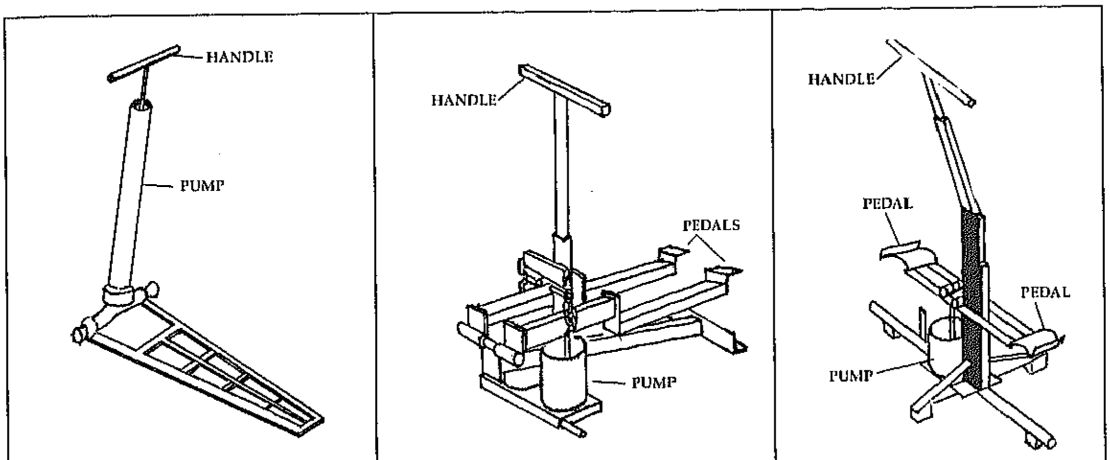


Bamboo type Treadle Pump (8.75 cm)



Metallic type Treadle Pump (12.5 cm)

Figure 6.3: Treadle pumps used in Eastern Africa



(a) MoneyMaker Hip Pump US$ 37 Pumping by hand	(b) MoneyMaker Plus US$ 60 Pumping by foot pedals	(c) Super MoneyMaker US$ 99 Pumping by foot pedals

2) Procedure

A treadle pump has two pedals and is operated by treading or pedalling (Figures 6.2 - 6.4). It can be made of bamboo or metal as shown. It has been observed that all members of a family may operate the pump. However, in Africa, it is operated more usually by young school-going boys and girls. In some cases, labour may be hired to operate the pump. The pump is generally operated for about three hours a day to irrigate about 1 acre (0.4 ha) of land. A well maintained TP can give a discharge of about 50 to 90 litres per minute at a depth of about 4.5 m. The highest discharge for a bamboo type can be 56 litres per minute at a depth of 4.5 m; 89 litres per minute for a metallic pump at a depth of 3 m; and 79 litres per minute for a concrete pump at a depth of about 5.5 m. The standard version can lift 5000 to 7000 litres of water an hour from wells, boreholes or surface water sources for a suction head of up to 7 metres. Because the pump employs the user's body weight and leg muscles, it is much less tiring than other manual pumps that utilize the upper body and arm muscles.

3) Costs and benefits

At US$ 70 in Kenya and approximately CFAF 63000 in Burkina Faso, the TP is reasonably priced. It is effective to operate a command area of about one acre (0.4 ha) and is most suited for marginal and small farmers. It is much more efficient than a diesel pump which usually sells for US$700-US$900 for 3-5 hp pumps. The average smallholder on 2-3 ha of rain-fed land makes less than US$ 750 of farm income while one using a treadle pump can record a per hectare gross margin of US$ 1400 for snow peas and French beans, US$ 450 for kale and US$ 600 for onions. A farmer can get 2-3 irrigated crops a year. Fabricated from locally available materials, it can be manufactured by metal working shops equipped with welders and simple hand tools such as those frequently found in large numbers in SSA capitals and many smaller towns.

4) Risks

Small farmers sometimes lack the collateral to secure loans for purchase of the treadle pumps. In addition, since crops are marketed either directly by farmers to consumers in local markets, through cooperatives, through middlemen, and through export contracts, this is risky because the farmer is not assured of a market.

Figure 6.4: Pumping water using a treadle pump

6.4 Methods of Surface Irrigation

There are many surface irrigation methods but the ones presented below are those that can be used by small scale farmers with low investment.

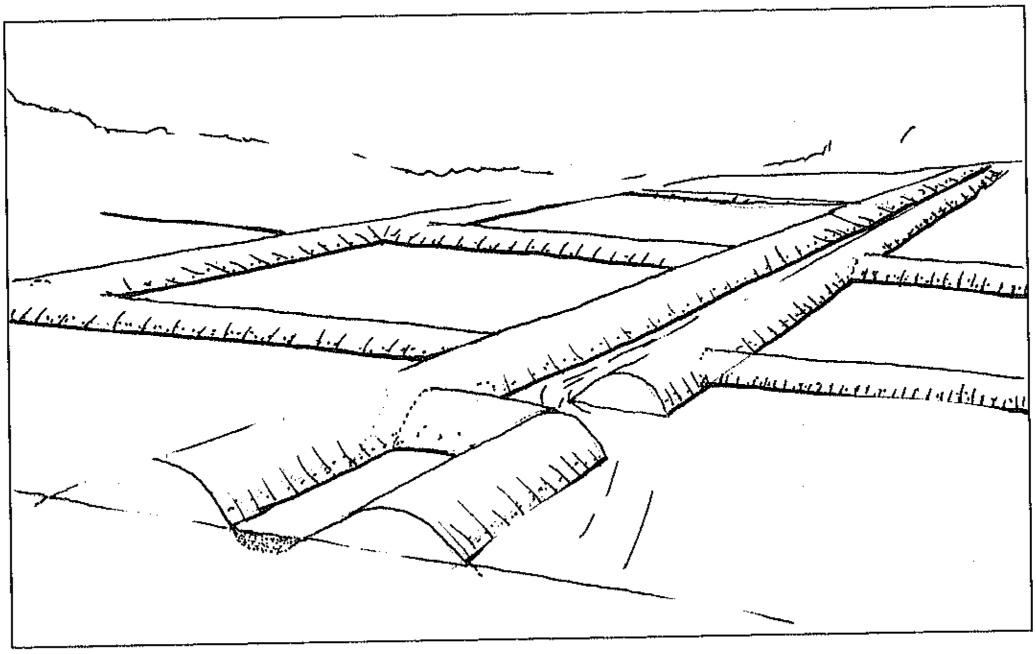
(1) Basin Irrigation

1) Description

An irrigation basin is a flat area of land that is bordered by a low raised earth bund on all sides with only an inlet for water (Figure 6.5). The bunds prevent the water from flowing to the adjacent basins or fields. Basin irrigation is suitable for crops that are unaffected by standing in water for long periods such as field crops and paddy rice. Other crops which are suited to basin irrigation include:

- pastures, e.g. lucerne, clover;
- trees, e.g. citrus, banana;
- crops which are broadcast, e.g. cereals – wheat, barley, sorghum, millet etc.;
- row crops such as tobacco.

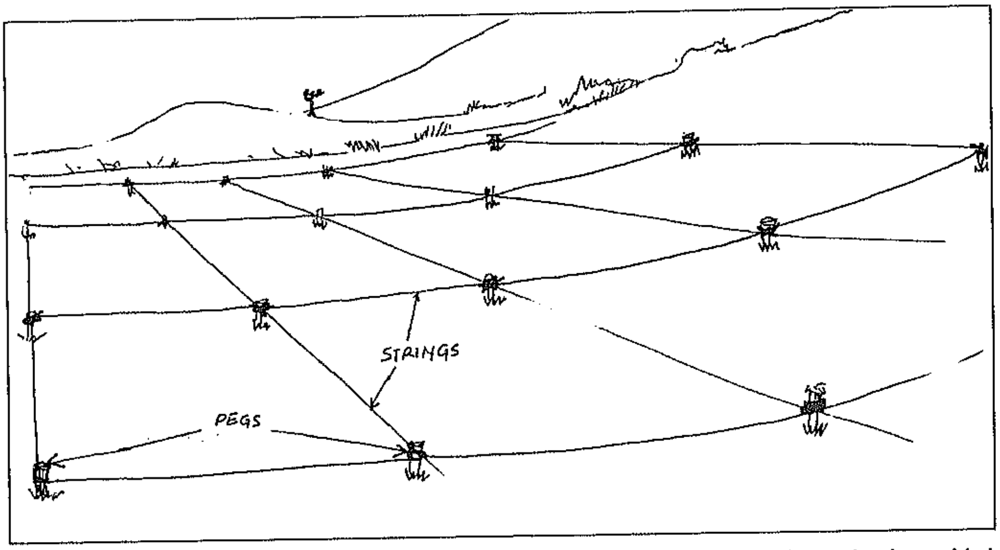
Figure 6.5: An irrigation basin



2) Procedure

Step1: Before construction of basins can begin, the location of the basins and bunds must be set out on the ground using pegs, string lines or chalk powder to mark the lines of the bunds which may be square or rectangular in shape (Figure 6.6). Setting out involves only straight lines. Terraces are set out so that the bunds are located along contour lines while maintaining small differences in elevation within each basin so that the amount of earth movement required to obtain a level land surface is small.

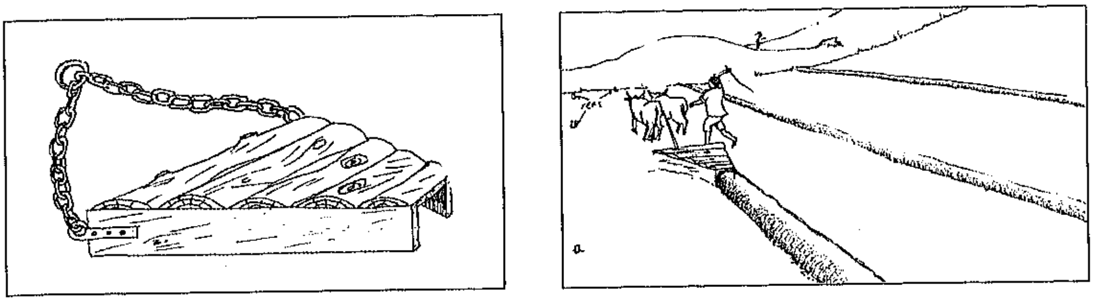
Figure 6.6: Setting out the markers along the lines of the bunds



Step 2: Forming both temporary and permanent bunds can be done by hand labour or by animal-powered equipment. When soil is gathered from an area close to the bund a 'borrow-furrow' is formed. This furrow can be smoothed out later or be used as a farm channel or drain. When forming bunds for terraces, soil should only be taken from the uphill side of the bund.

Bunds are formed by pulling an A-frame (Figure 6.7) to move soil that has been loosened to a depth of 15 cm by ploughing. This consists of two 2 m long boards set on edge and cross-braced, with a 1.5 m opening at the front and a 30 cm opening at the rear. The boards act as blades for cutting into the soil and crowding it into a ridge or bund. This bund is then properly compacted so that leakage cannot occur. Compaction can be obtained by walking animals or people on top of the bund, or by using a roller drum filled with water or sand.

Figure 6.7: Using a wooden A-frame to make bunds



Step 3: Smoothing the land involves very careful levelling of the land within each basin. On flat land the minor high and low spots are smoothed so that the differences in level are less than 3 cm. This can be done by hand or by an animal-drawn land plane depending on the size of the basin. However, 3 cm level differences are almost impossible to judge by eye and only when applying water will it become obvious where high and low spots still exist. Make several attempts until a flat bed is obtained. Levelling rice basins can be much simpler because these are first cultivated and then filled with water. As the water surface is level, it will be obvious where the high spots are. These areas are smoothed out.

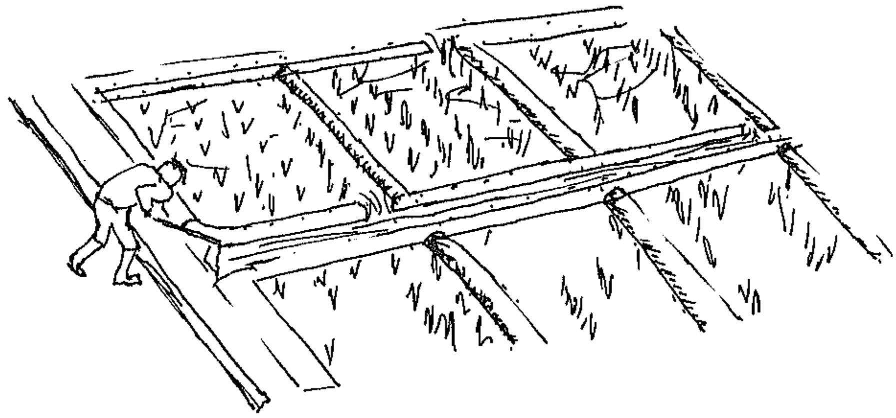
3) Costs and benefits

The main cost of making basins is the levelling of the land depending on its original terrain. Steep land has to have many narrow basins and this is expensive to make especially if one is hiring animals or machinery to do the work. The benefits of this irrigation method are that it is suitable for many types of crops and the basins can remain for a long time if well compacted and maintained. On heavy clay soils, rice has been grown in level basins for hundreds of years.

4) Risks

Bunds are susceptible to erosion which may be caused by rainfall, flooding or the passing of people when used as footpaths. Rats may dig holes in the sides of the bunds. It is therefore important to check the bunds regularly, notice defects and repair them instantly, before greater damage is done. Before each growing season, the basins should be checked to see that they remain level. During pre-irrigation it can easily be seen where higher and lower spots are; these should be smoothed out. Also, the field channels should be kept free from weeds and silt deposits to allow for water to flow fast, freely and with minimal loss.

Figure 6.8: Basin irrigation of paddy



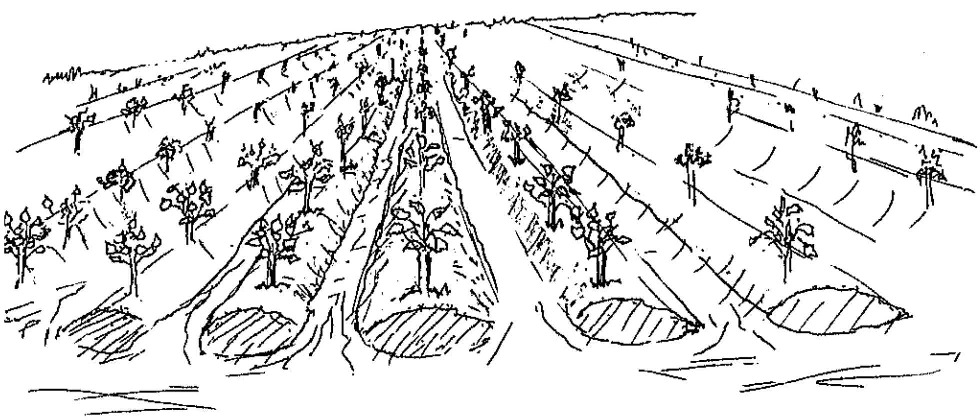
(2) Furrow Irrigation

1) Description

Furrows are small channels which carry water down the land slope between the crop rows. Water infiltrates into the soil as it moves along the slope. The crop is usually grown on the ridges between the furrows (Figure 6.9). Water may be drawn from the field furrow onto the irrigation furrow using a siphon bent so that it can go over the ridge. Furrow irrigation is suitable for all row crops and for crops that cannot stand in water for long periods such as:

- row crops - maize, sunflower, sugarcane, soybean;
- crops that would be damaged by inundation - tomatoes, vegetables, potatoes, beans;
- fruit trees - citrus, grape.

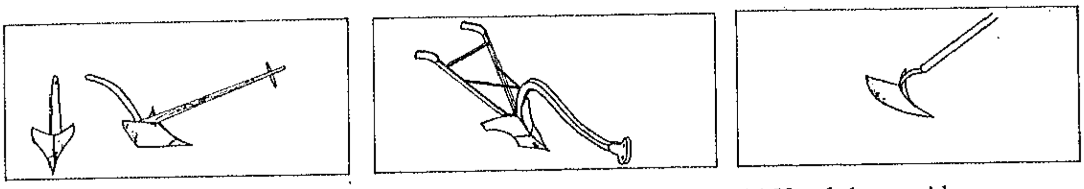
Figure 6.9: Furrow irrigation



2) Procedure

Furrows are constructed with an animal drawn or hand-drawn wooden or metal ridger (Figures 6.10 and 6.11). The following steps are taken to construct furrows: setting out; forming one or several parallel ridge(s).

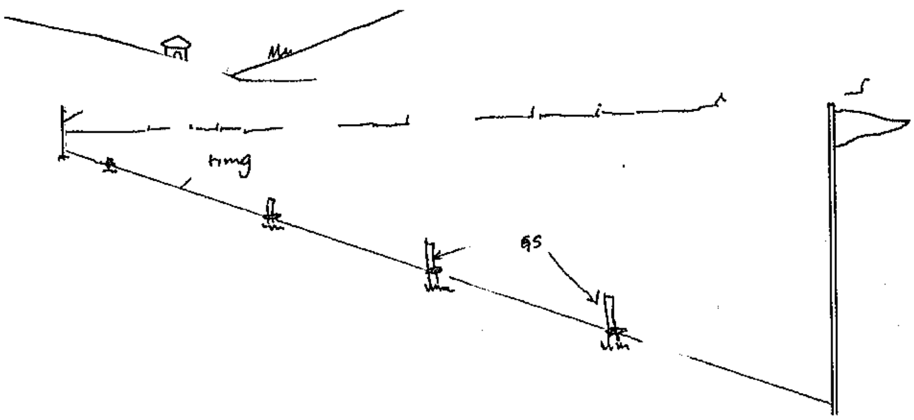
Figure 6.10: Types of ridgers



(a) Wooden ridger, animal drawn (b) Metal ridger (c) Hand-drawn ridger

Step 1: Set out a straight line in the field along the proposed line of furrows. This can be done by setting up ranging poles or marking a line on the ground with chalk powder or small mounds of earth. An experienced ploughman should be able to plough along the line by aligning the poles or earth mounds by eye (Figure 6.11).

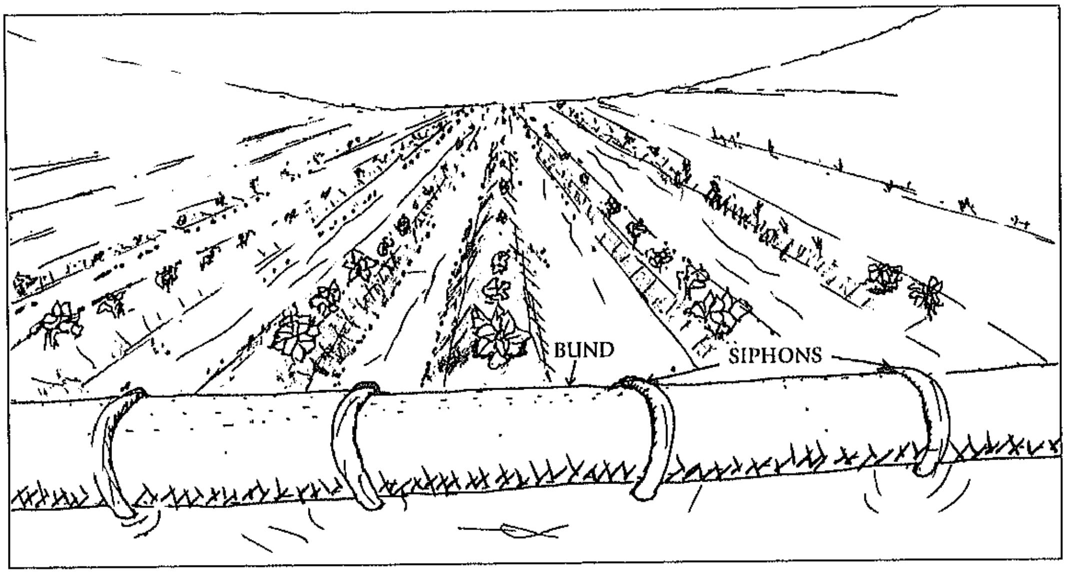
Figure 6.11: Setting out a straight line for a furrow with markers



Step 2: The ridger is moved along the line. The resulting furrow should be straight. If not, the area should be ploughed again and the procedure repeated. The length of the furrow may run the entire length of the field. But furrows should not be made too long so as to avoid over-irrigating the upper part of the furrow before water runs to the end of the furrow. Furrows should not be too wide – as a general rule the recommended row spacing of the particular crop should determine the width of the furrow.

To irrigate a furrow, a siphon leads water from the feeder channel to the furrow. Run water along the furrow until it reaches near the end of the furrow and then stop the flow by removing the siphon or closing the entrance to the furrow.

Figure 6.12: Furrow irrigation using siphons



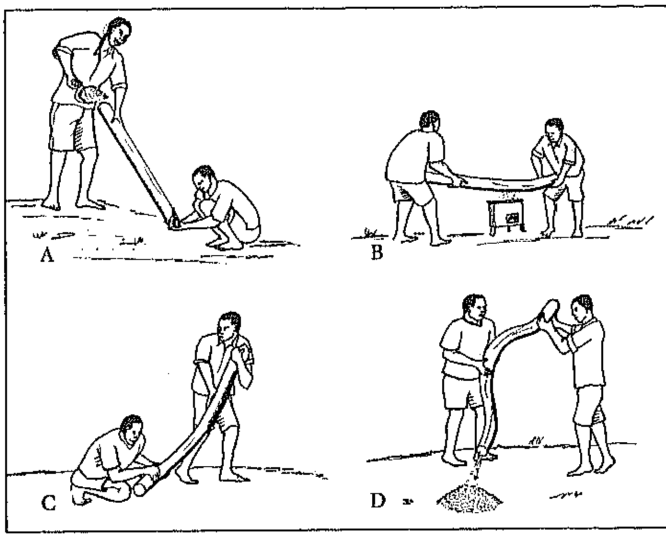
3) Costs and benefits

The main cost is the initial construction of furrows as well as their regular maintenance. This construction can be done using family labour at minimal cost. Benefits of furrow irrigation include the wide range of crops that can be grown with this method and the economy of water use when water application is properly managed.

4) Risks

During irrigation it should be checked if water reaches the downstream end of all furrows. There should be no dry spots or places where water stays ponding. Overtopping of ridges should not occur. The field channels and drains should be kept free from weeds.

Figure 6.13: How to bend a siphon



A. Close one end of PVC pipe. Fill pipe with sand.

B. Heat over a fire the area to be bent while turning siphon.

C. Bend siphon while hot to the desired shape.

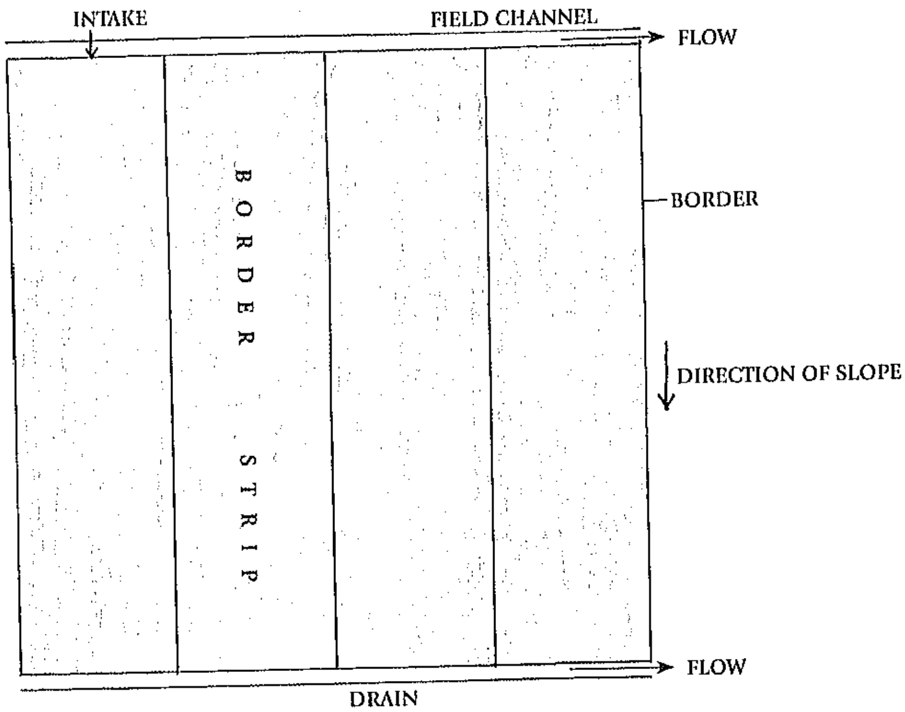
D. Empty the siphon.

(3) Border Irrigation

1) Description

Borders are long, sloping strips of land separated by earth bunds. They are sometimes called border strips. Irrigation water can be fed to the border in several ways: opening up the channel bank, using small outlets or gates or by means of siphons. A sheet of water flows down the slope of the border, guided by the bunds on either side (Figure 6.14). In contrast to basin irrigation these bunds are not to contain the water for ponding but merely to guide it as it flows down the field. This method is suited for large scale mechanised farms but can also be adapted to small farms with loam and clay soils with medium infiltration rates. It is most suitable for close growing crops such as pasture or lucerne.

Figure 6.14: A field with border strips



2) Procedure

Create borders the same way you create bunds for basin irrigation. The strip of land between the borders should be narrow so that water can easily spread across it as it flows to the bottom of the border strip.

Irrigate the border by diverting a stream of water from the channel to the upper end of the border. The water flows down the slope. When the desired amount of water has been delivered to the border, the stream is turned off. This may occur before the water has reached the end of the border. There are no specific rules controlling this decision. However, if the flow is stopped too soon there may not be enough water in the border to complete the irrigation at the far end. If it is left running for too long, then water may run off the end of the border and be lost in the drainage system, also causing damage to the border.

3) Costs and benefits

The main cost is that of creating the bunds. For a small plot, these can be created using family labour at minimal cost.

4) Risks

There are no unique risks related to border use except the danger of over-irrigation or under-irrigation especially at the bottom end of the border. Pay particular attention to the stream size and the point at which to close the stream – on clay soils when the water covers 60% of the length of the field and on sandy soils when it covers 80% of the field length. Use a stick to mark this point and stop the stream when the water reaches it.

Repair any damage on the bunds promptly and the field channel and drains are to be weeded regularly. By checking frequently and carrying out immediate repairs where necessary, further damage is prevented.

(4) Water harvesting and spate irrigation

1) Description

When it rains, much of the water runs across the field, down the road or natural channel to a stream, river or lake. From there it may end up in a larger lake or bigger river and on to the ocean. This water is called runoff. Water harvesting is a method of irrigation practised by collecting runoff and leading it to the field where the water is ponded until absorbed into the soil.

Spate irrigation is unique to semi-arid environments. It is found in the Middle East, North Africa, West Asia, East Africa and parts of Latin America. Flood water from mountain catchments is diverted from river beds (wadis) and spread over large areas.

Since runoff and spate flows continue only for as long as the rain is falling and stop shortly afterwards depending on the intensity of the shower, the ground cover, soil properties and the size of the catchment, this water must be captured even as the rain falls. The farmer has to be committed enough to go out in the rain and sometimes in the middle of the night to harvest this runoff and lead it to his land. Alternatively, the runoff or spate flow may be directed to a reservoir (pan) and used later.

2) Procedure

i) Observe the runoff: Observe and assess the source of runoff, amount, direction of flow and slope of the land. Draw up a checklist of questions to help you do this, such as:

- What is the slope?
- What is the ground cover like?
- How easily will water percolate into the soil, and into the subsoil?

- How much runoff in a heavy rainstorm is there likely to be from different parts of the catchment?

Draw up a list of all the possible questions that you need to answer in order to understand fully the nature of the runoff.

ii) Mark contour lines: Using an A-frame or line-level mark contour lines at regular intervals down the slope. While doing this, try to identify possible dam sites. It may be necessary to call in an expert for this exercise.

iii) Design the water-harvesting system: With a thorough understanding of the piece of land and a common vision of what the various people working on it would like, the detailed siting can begin. If there are enough people, have them work on ideas in separate groups. This will lead to many creative options being developed.

Consider the following in particular:

- **Runoff sources.** How can roads and paths be designed to carry runoff from above them (and off the road or path itself) to a dam, pond or field? Roads are a common cause of erosion if the runoff from them is not carefully controlled. But if they are well designed, they are a good potential source of water. Consider also roofs, sports fields, land higher up in the catchment, rocks, and land with poor ground cover. Where do water-harvesting ditches need to be sited to control the runoff they will produce?
- **Dams and ponds.** Where will they get their water from? How can their spillways be designed to spread water rather than just run it back into the same water course? Can spillways be designed to take water along the contour to the next water course?

When linking the ideas from the participants, put into focus the following principle considerations of water harvesting:

a. **Top down.** Start work at the highest point of the piece of land. Control water there first, and then work your way down the slope, putting your design into effect.

b. **Spread and sink**. Unless you are specifically carrying water to a dam, pond or tank, sinking water (allowing it to seep into the soil) is the aim of all water management. Remember that in the long term it will be much better if the dams are filled from underground water moving downslope, rather than from surface runoff which carries silt.

c. **Spillways.** Pay special attention to all spillways. These are the weak links in any water-harvesting earthwork. You must design them to stand up to the worst storm. This includes spillways from a dam, pan or pond, from ditches, or from a small pit catching water off a roof. Use the "spread and sink" principle on the spillways.

d. **Ground cover.** Always aim for maximum ground cover. In the end, ground cover is the best water-harvester of all. You can design sports fields so that they have banks all round to catch the water; but ensure also that the fields are as well covered by grass. In the long term, the grass will mean much more than the banks in terms of sinking water.

Once everyone agrees to the design for the whole piece of land, you are ready to implement. The plan is the guide. It can, of course, be adapted as you go along. Many people forget that flexibility in creativity is the mother of beauty! Follow the four principles of water harvesting above. Learn and understand as many of the techniques for water harvesting as you can. There are many of them: pits, swales or *fanya chini*, contour ditches, bunds, *fanya juu*, infiltration pits, net and pan, tied ridges, and stone contour barriers.

If the crop being irrigated is an established pasture or trees (e.g. fruit trees – mangoes, oranges etc.), water may be led directly to the pasture or to the basin of each tree.

3) Costs and benefits

A water harvesting or spate irrigation system that feeds water directly to the field requires only minimal hand-made structures – trenches, gates and embankments - which the farmer can make with family labour. However, constructing a pan to store spate water for multiple users like a community may require substantial costs of hiring an earth mover.

The benefits of water harvesting include the following:

- Water harvesting makes use of runoff water that would otherwise go to waste particularly in arid and semi-arid regions.
- Runoff water brings with it many useful soil nutrients suitable for improving soil fertility.
- Water diverted from roads means reduction of erosion and damage to the road.
- It makes it possible to raise a crop in an arid or semi-arid zone where rainfall is unreliable and/or poorly distributed.

4) Risks

Water harvesting and spate irrigation are risky because of both the unpredictable nature of the floods and the frequent changes to the river beds from which the water is diverted. If runoff water is not well-controlled, it may cause soil erosion in the field. Another risk is that irrigation has to be done under rain and sometimes with poor lighting at night.

6.5 Sprinkler Irrigation

1) Description

Sprinkler irrigation is a method of applying irrigation water which is similar to natural rainfall. Water is pumped through a pipe system and then sprayed onto the crops through rotating sprinkler heads so that it breaks up into small water drops which fall to the ground. The pump supply system, sprinklers and operating conditions must be designed to enable a uniform application of water. Sprinkler irrigation can be operated without a pump if the water is piped from a high gravity head that is capable of giving the required pressure for turning the sprinklers. Under small scale SSA farming systems, only gravity sprinkler irrigation is considered as sustainable.

Sprinkler irrigation is suited for most row, field and tree crops and water can be sprayed over or under the crop canopy. But large water drops can damage leaf crops such as lettuce. It is also adaptable to any slope, whether uniform or undulating and to most soils. The average application rate from the sprinklers (in mm/hour) is always chosen to be less than the basic infiltration rate of the soil so that surface ponding and runoff can be avoided. A good clean supply of water, free of suspended sediments, is required to avoid problems of sprinkler nozzle blockage.

The most common type of sprinkler system layout consists of a system of lightweight aluminium or plastic pipes which are moved by hand. The rotary sprinklers are usually spaced 9-24 m apart along the lateral which is normally 5-12.5 cm in diameter. This is so it can be carried easily. The lateral pipe is located in the field until the irrigation is complete. The pump is then switched off and the lateral is disconnected from the mainline and moved to the next location. It is re-assembled and connected to the mainline and the irrigation begins again. The lateral can be moved one to four times a day. It is gradually moved around the field until the whole field is sufficiently irrigated. This is the simplest of all systems. Some systems may use more than one lateral to irrigate large areas.

2) Procedure

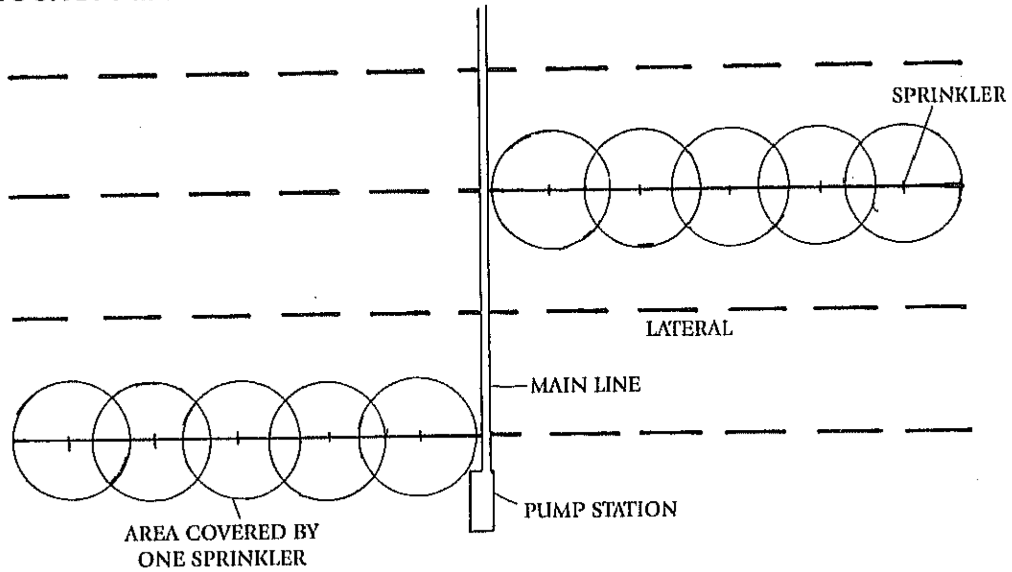
A typical sprinkler irrigation system consists of the following components:

- Pump unit (or high level piped gravity intake)
- Mainline and sometimes sub-mainlines
- Laterals
- Sprinklers

The pump unit is usually a centrifugal pump which takes water from the source and provides adequate pressure for delivery into the pipe system. A high level from a point in the river or stream can also provide sufficient head to operate the sprinklers.

The mainline - and sub-mainlines - are pipes which deliver water from the pump to the laterals. In some cases these pipelines are permanent and are laid on the soil surface or buried below ground. In other cases they are temporary, and can be moved from field to field. The main pipe materials used include cement, plastic or aluminium alloy. The laterals deliver water from the mainlines or sub-mainlines to the sprinklers. They can be permanent but more often they are portable and made of aluminium alloy or plastic so that they can be moved easily.

Figure 6.15: Parts and layout of a sprinkler irrigation system



3) Costs and benefits

A major cost in using sprinkler irrigation is the heavy initial capital required to procure the pump, pipes and sprinklers. It also requires a large labour force to move the pipes and sprinklers around the field. In some places such labour may not be available and may also be costly.

The main benefit of this system is that it sprays water that emulates rain and distributes it well on the land with little loss.

4) Risks

A sprinkler irrigation system requires that the farmer has some prior knowledge about irrigation so that he can select sprinklers of the right size for the crop and the pressure delivered by the pump or the gradient from the gravity intake. The system has to be regularly maintained as sprinklers easily block if the irrigation water is not clean.

Figure 6.16: Irrigating by sprinklers

6.6 Drip Irrigation

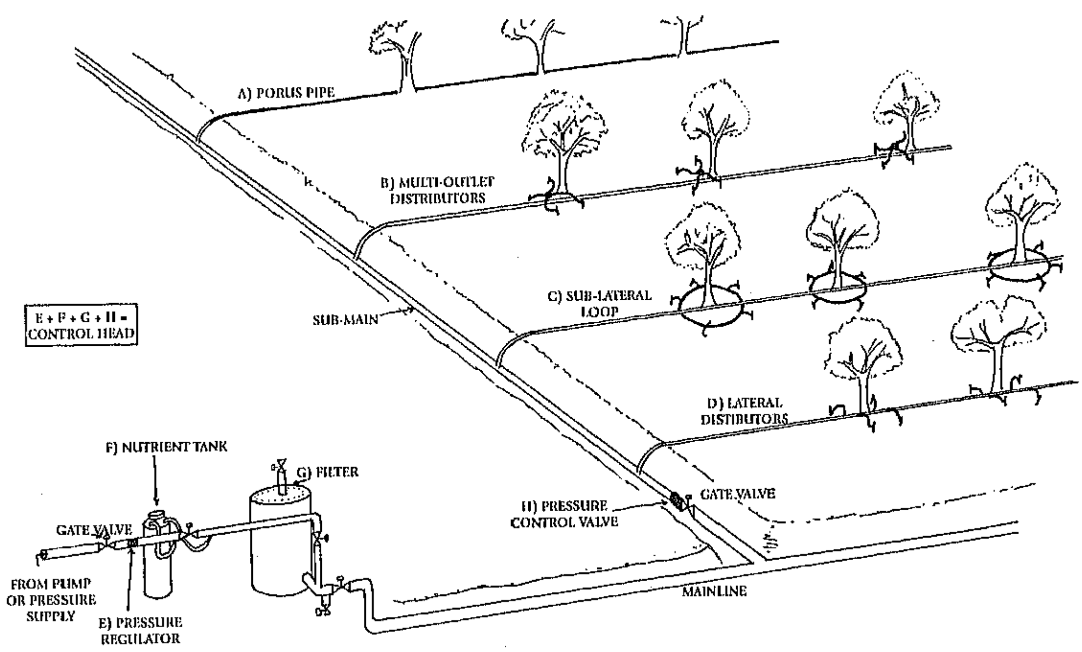
1) Description

Drip irrigation is also called trickle irrigation. Water is conveyed under pressure through a pipe system to the fields, where it drips at very low rates (2-20 litres/hour) onto the soil through emitters or drippers which are located close to the plants. Only the immediate root zone of each plant is wetted. Therefore this can be a very efficient method of irrigation i.e. one that wastes very little or no water at all.

With drip irrigation, water applications are more frequent (usually every 1-3 days) than with other methods and this provides a very favourable high moisture level in the soil in which plants can flourish. Drip irrigation is most suitable for row crops (vegetables, soft fruit), tree and vine crops where one or more emitters can be provided for each plant. Generally only high value crops are considered because of the high capital costs of installing a drip system.

Drip irrigation is adaptable to any slope. Normally the crop would be planted along contour lines and the water supply pipes (laterals) would be laid along the contour also (Figure 6.17). Drip irrigation is suitable for most soils. On clay soils water must be applied slowly to avoid surface water ponding and runoff. On sandy soils higher emitter discharge rates will be needed to ensure adequate lateral wetting of the soil.

Figure 6.17: Drip irrigation system layout



2) Procedure

A typical drip irrigation system (Figure 6.17) consists of the following components:

- Pump unit (or high head river intake)
- Control head
- Main and sub-main lines
- Laterals
- Emitters or drippers.

The pump unit takes water from the source and provides the right pressure for delivery into the pipe system.

The control head consists of valves to control the discharge and pressure in the entire system. It may also have filters to clear the water. Mainlines, sub-mains and laterals supply water from the control head into the fields. They are usually made from PVC or polyethylene hose and should be buried below ground because they easily degrade when exposed to direct solar radiation. Lateral pipes are usually 13-32 mm diameter. Emitters or drippers are devices used to control the discharge of water from the lateral to the plants.

6.7 Smallholder drip irrigation systems

Crop failure from unreliable and poorly distributed rains is widespread and on the increase in SSA arid and semi-arid lands (ASAL), leading to increased food insecurity. In these ASAL, some form of irrigation is necessary to meet water needs of horticultural crops. Large, capital-intensive irrigation projects tend to perform poorly compared to smallholder-irrigation schemes. Poor management results in the unfair distribution of water, and in soils becoming waterlogged and saline, leading to some schemes being abandoned. Drip irrigation provides good water control by delivering water near the plant, enabling the farmer to grow crops with much less water than with other methods.

1) Advantages

- For a relatively low initial investment (US $15 to $85) a small-scale farmer can buy and set up a drip-irrigation system. If used to grow crops for market, this investment will pay itself within the first season and lead to increased household food production, especially during extended dry periods.
- Drip irrigation requires little water compared to other irrigation methods. About 40-80 litres per day are needed per 100-200 plants.
- The small amount of water reduces weed growth and limits the leaching of plant nutrients down in the soil.
- Inorganic fertilizer or manure tea (made by mixing manure with water and filtering) can be applied efficiently to the plants through the drip system.

2) Disadvantages

- Most drip-irrigation equipment must be imported, so is not widely available.
- Most experience in using drip irrigation is confined to commercial farmers and research stations.
- Drip-irrigation systems are subject to clogging, especially if poor-quality water is used.
- Farmers require training to manage drip irrigation successfully.

3) Requirements

- Filter, drip tape or polyethylene pipe and drip emitters, connectors.
- Water source (for direct-connected systems) or reservoir such as 20-litre bucket or 100-200-litre drum.
- Material for constructing a stand or platform for the bucket, drum or water tank.

4) Risks

One of the main problems with drip irrigation is blockage of the emitters. All emitters have very small waterways ranging from 0.2-2.0 mm in diameter and these can become blocked if the water is not clean. Thus it is essential for irrigation water to be free of sediments. If this is not so then filtration of the irrigation water will be needed.

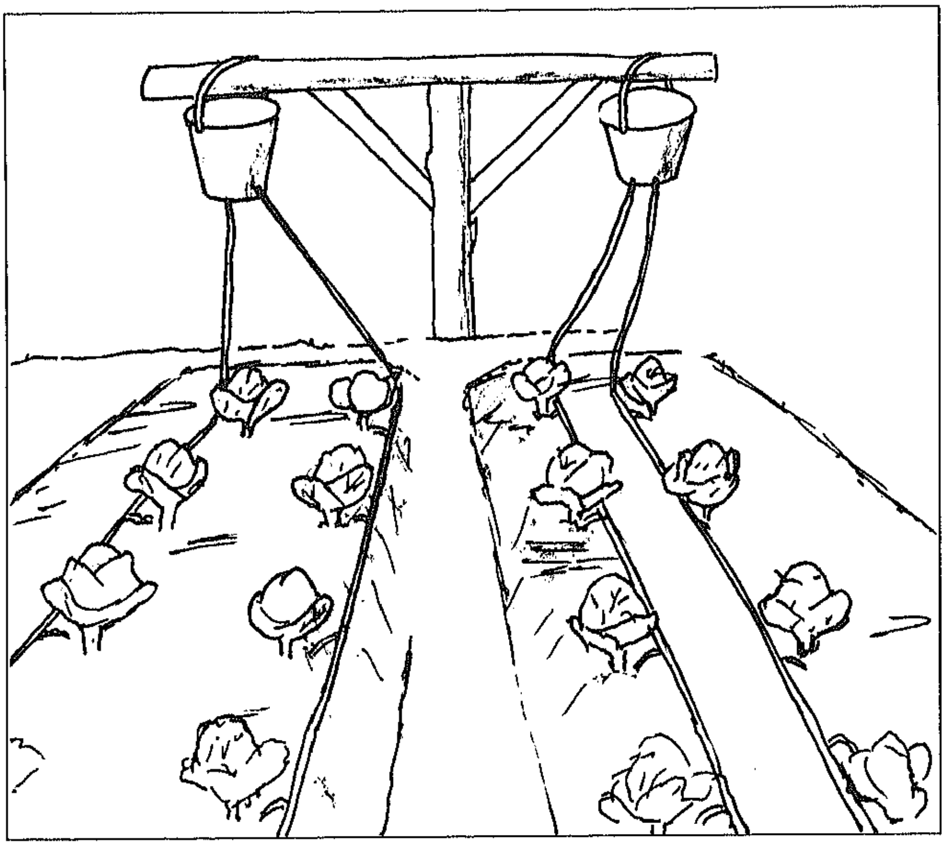
Blockage may also occur if the water contains algae, fertilizer deposits and dissolved chemicals which precipitate such as calcium and iron. Filtration may remove some of the materials but the problem may be complex to solve and requires an experienced engineer or consultation with the equipment dealer.

Drip irrigation is particularly suitable for water of poor quality (saline water). Dripping water to individual plants also means that the method can be very efficient in water use. For this reason it is most suitable when water is scarce.

(1) Bucket drip system

The bucket drip system consists of two drip lines, each 15-30 m long, and a 20-litre bucket for holding water. Each of the drip lines is connected to a filter to remove any particles that may clog the drip nozzles. The bucket is supported on a bucket stand, with the bottom of the bucket at least 1 m above the planting surface. One bucket system requires 2-4 buckets of water per day and can irrigate 100-200 plants with a spacing of 30 cm between the rows. For crops such as onions or carrots, the number of plants can be as many as the bed can accommodate. A bucket system currently costs about Kenya shillings (KES) 900 (US$ 15). A farmer growing for the market can usually recover this investment within the first crop season.

Figure 6.18: Bucket drip-irrigation system

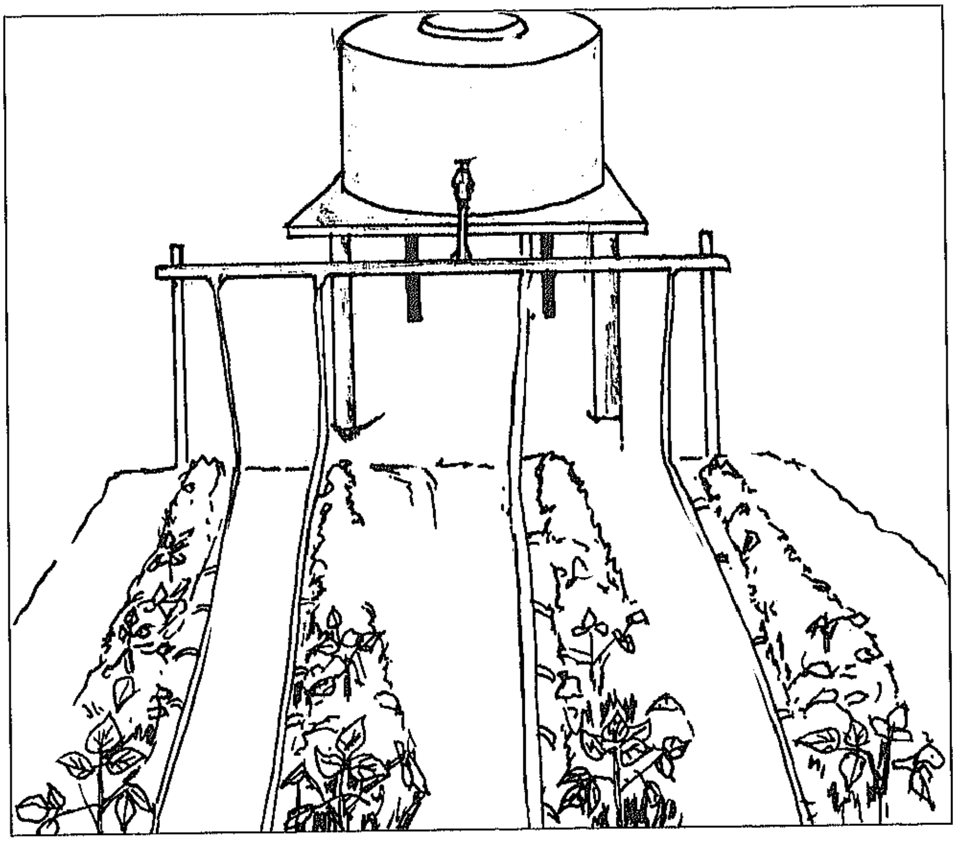


(2) Drum Drip Irrigation System

The drum system is a combination of several bucket systems but modified to use a water supply from a 100 to 200-litre drum instead of a 20-litre bucket. It consists of drip lines measuring 15-30 m long, a lateral line to which the drip-lines are connected (including a gate valve) and a drum or a small tank as the water reservoir, raised 1 m above the soil. The equivalent of five to ten bucket kits can be connected in this system. The lateral line is made of 2.5 cm (1-inch) diameter PVC, steel or polyethylene pipes. Connecting tees are used for each pair of drip lines.

A drum system equivalent to five bucket systems can irrigate 500-1000 plants planted with 30 cm between the rows. Such a system requires about 100-200 litres of water a day, depending on the environment and crop. It costs a total of KES 5,000 (US$ 85). For comparison, a crop of cabbage yields a gross return of KES 15,000 (US$ 250).

Figure 6.19: Drum drip-irrigation system



Note: Bucket systems are produced by Chapin Watermatics Inc, 740 Water St, Watertown, NY 13601, USA, and are distributed at low cost. Bucket, drum, one-eighth-acre garden, and orchard kits are currently being promoted by the Kenya Agricultural Research Institute (KARI). For more information, contact Isaya Sijali, KARI, Kenya.

CHAPTER 7:

AGRO-FORESTRY

7.1 Overview

(1) Meaning of Agro-forestry

Land degradation is the lowering of the productive capacity of the land through processes such as soil erosion, loss of soil fertility and soil salinity. Land degradation can be temporary but may become permanent if left unchecked. Severe land degradation is widespread in developing countries especially those in SSA, and fairly common in developed countries as well. The current interest in agricultural sustainability is an attempt at arresting and, if possible, reversing current trends in land degradation.

Trees can be effective tools for land restoration, and agro-forestry is emerging as an important alternative to conventional cropping systems that tend to cause land degradation. Agro-forestry may take many forms such as:

- trees intercropped with pasture in an extensive system,
- trees planted in bands or belts on cropland or pasture, and
- separate areas of forest and crops or pastures in the same property.

(2) Motivations to Plant Trees

The motivations to plant an improved fallow plot as established through a survey in Zambia are sometimes because soils are tired, fertilizer is too expensive, or the maize harvest does not last all year until the next harvest. Any one of these reasons is enough for a farmer to consider planting an improved fallow which would include grass and trees.

(3) Constraints to Planting an Improved Fallow

In rural Africa, farmers can either buy or barter or get fertilizer on credit. But, whereas women, especially from female-headed households, mostly barter farm produce for fertilizer, men mostly buy fertilizer. In many parts of SSA seasonal credit for smallholder farm inputs including fertilizer is not available. Manure is also mostly used on vegetable gardens instead of maize fields. Although crop rotations are maintained as a soil fertility measure, this does not satisfy the soils' need for more fertility. For these reasons, it becomes necessary to use agro-forestry to improve soil fertility.

7.2 Benefits of Agro-forestry

Research over the past 20 years has confirmed that agro-forestry can be more biologically productive, more profitable, and be more sustainable than forestry or agricultural monocultures. The definition of agroforestry used in this manual excludes orchards.

Research has also confirmed that agro-forestry systems can include the following benefits:

- They can control runoff and soil erosion, thereby reducing losses of water, soil material, organic matter and nutrients.
- They can maintain soil organic matter and biological activity at levels satisfactory for soil fertility. This depends on an adequate proportion of trees in the system - normally at least 20% ground cover of trees to maintain organic matter.
- They can maintain more favourable soil physical properties than agriculture, through organic matter maintenance and the effects of tree roots.
- They can lead to more closed nutrient cycling than agriculture and hence to more efficient use of nutrients. This is true to an impressive degree for forest garden/farming systems.
- They can check the development of soil toxicities, or reduce existing toxicities - both soil acidification and salinization can be checked, and trees can be employed in the reclamation of polluted soils.
- They utilise solar energy more efficiently than monocultural systems - different height plants, leaf shapes and alignments all contribute.
- They can lead to reduced insect pests and associated diseases.
- They can be employed to reclaim eroded and degraded land.
- They can create a healthy environment - interactions from agro-forestry practices can enhance the soil, water, air, animal and human resources of the farm.
- They can moderate microclimates. Shelter given by trees improves yields of nearby crops and livestock. Shade in dry climates can reduce stress on livestock.
- Agro-forestry can augment soil water availability to land-use systems.
- Nitrogen-fixing trees and shrubs can substantially increase nitrogen inputs to agro-forestry systems.
- Trees can increase nutrient inputs to agro-forestry systems by retrieval from lower soil horizons and weathering rock, especially micronutrients.

- The decomposition of tree litter and prunings can substantially contribute to maintenance of soil fertility. The addition of high-quality tree prunings (i.e. high in Nitrogen but which decay rapidly) leads to increases in crop yields.
- The release of nutrients from the decomposition of tree residues can be synchronised with the requirements for nutrient uptake of associated crops. While different trees and crops will have different requirements, and there will always be some imbalance, the addition of high-quality prunings to the soil at the time of crop planting usually leads to a good degree of synchrony between nutrient release and demand.
- In the maintenance of soil fertility under agro-forestry, the role of roots is at least as important as that of above-ground biomass.
- Agroforestry can provide a more diverse farm economy and stimulate the whole rural economy, leading to more stable farms and communities. Economic risks are reduced when systems produce multiple products.

7.3 Agro-forestry Best Practices

(1) Information Dissemination

The task of tree propagation and improvement has traditionally fallen on individual farmers. The local knowledge on propagation of trees through collection of seeds or cuttings from local indigenous trees tends to be localized. Often trees for fuelwood and fodder arise naturally and are left uncut at field boundaries. Other trees are planted for fruit and cash. Even economically useful palms are allowed to regenerate naturally and are protected where they arise.

The best practice is to obtain and use local knowledge on suitable indigenous tree species and their methods of propagation.

(2) Seed Quality

Fruit tree seeds are sometimes collected from poor quality fruit as the best fruit is sold fresh. Farmers should maintain genetic purity through the isolation of varieties and the elimination of unwanted or inferior plants. The seeds which are collected should not be those which are most accessible especially those lying on the ground. These are vulnerable to attack by seed eating insects and fungal pathogens. Seeds harvested from small trees which are easy to reach may result in a greater frequency of small trees in subsequent populations.

Often all the non-indigenous trees in an area, or even a whole country, have arisen from an extremely limited genetic base introduced as one small seed lot, commonly during Africa's colonial days. The original introduction may not have been selected for any useful characters, or indeed may have been selected for ornamental and amenity properties, which may well not be the qualities now sought for multipurpose use.

The best practices should include seed selection on the basis of sought-after characteristics such as resistance to long dry spells (to resist drought), woody branching (for fuel wood or construction), fast growth, leaf production and nutritional value (for fodder trees), and so on.

(3) Agro-forestry Trees

Good agro-forestry practices dictate that farmers use trees which have a root and canopy structure suitable for integration into agro-forestry systems. These trees are grown adjacent to, or among, annual field crops. They must also help improve or stabilize soil properties, for example through the ability of the tree to fix nitrogen through symbiosis with nitrogen fixing bacteria, or through the incorporation of increased levels of organic matter when the leaves are applied as a green manure.

Agro-forestry species must not, however, display negative allelopathic effects on the adjacent crops or compete aggressively for water and nutrients. That is to say, their presence should not injure or have a negative effect on the growth of another species. Trees which fulfil these criteria include *Leucaena leucocephala, Gliricidia sepium, Calliandra calothyrsus* and *Faidherbia albida*. These are often not indigenous to the areas in which they are utilized and may not, therefore, be locally available. If the required seed cannot be obtained from national sources, it must be obtained elsewhere, including the international seed market.

(4) Need for Provenance Tested Seed

Multipurpose trees come, at present, almost exclusively from wild, 'unimproved' populations. Considerable individual variation exists within a single species. Many of the most important species are self-incompatible so seed characters are inherited from different parent trees, increasing the variation between individual seeds. Trees grown from seeds collected from a number of trees within one area, when compared with trees from seeds of the same species from a different area, will often exhibit marked differences in growth rates, growth form, pod production, tolerance to environmental stresses, thorniness and the presence of anti-nutritional factors. Even seeds collected from an individual tree will produce progeny with highly variable characteristics.

(5) Seed Quality on the International Market

Seeds available on the international market are often subject to the same quality constraints as those collected at farm level. They are collected contractually on request with the emphasis on quantity, often at the expense of quality. Seeds are collected from trees in the population which may not necessarily display ideal properties. In the interests of labour saving, each individual tree is often stripped of seed, including those which are under or over-ripe.

(6) Finance

To purchase seeds on the international market it is necessary to pay for the seeds, certification and transport in advance, by bankers order, in foreign currency. Many of those requiring seeds are farming at subsistence levels and those who have formed into self help groups and NGOs are equally short on funding. It is difficult for NGOs or individuals to obtain sufficient funds to meet the high cost of overseas seed purchase. For these groups collection and use of local materials are recommended.

(7) Seed Distribution Networks

Tree seeds can be obtained free of charge from a few sources, but each of these has limitations:

- the DANIDA Forest Tree Seed Centre in Denmark. DANIDA grade their available seeds in terms of the quality of information and viability of seed lots. Good quality seeds which have full collection details available are reserved for scientific research programmes or seed orchards. Small groups which wish to conduct 'look-see' trials appear, from the DANIDA policy statements, to be excluded from receiving high quality seed.
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- ICRAF in Nairobi, Kenya will supply seed to research projects on the basis of a trials network in return for a full scientific report on the results. Other groups which are not necessarily research based are thus excluded from receiving quality tested seed of known provenance.
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